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Implementation of the maturity method into precast concrete applications.

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IMPLEMENTATION OF THE MATURITY METHOD INTO PRECAST CONCRETE APPLICATIONS

by

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ABSTRACT

The personnel at Prestressed Systems Incorporated (PSI) suspected that use of the zero slump test cylinders to measure the compressive strength of hollowcore concrete was not reliable. If a test cylinder failed only by a chipped edge while being tested for compressive strength, it was not useful for determining the time at which the prestressing force in the tendons can be transferred into the bed of hollowcore.

A more reliable method was sought to quantify the compressive strength of zero slump concrete at the time of tendon release. The method should also provide real-time information on the progress of concrete strength development and result in savings associated with the mix design, labour and accelerated curing energy optimization.

A non-destructive Maturity Method has been proven effective in other studies focused on determining compressive strength of concrete. This research describes the implementation of the Maturity Method in the precast hollowcore plant at PSI.

Experimental results revealed that the temperature-time factor maturity function with a 0 °C datum temperature is appropriate for modeling the strength development of hollowcore concrete. A statistical approach was used to calculate required values of maturity index that corresponded to the two most commonly used release strengths.

A slippage study was used to evaluate the performance of the maturity method. Since, the number of hollowcore slabs with out of tolerance initial and final slippage were significantly reduced after the implementation of the maturity method, the study showed that the maturity method was reliable in measuring concrete compressive release strength and the time to detension the prestressing strands.

A discussion on how the maturity method affects hollowcore production

optimization revealed that by providing real-time information the maturity method can lower production costs with respect to mix design, labour, and curing energy.

ACKNOWLEDGMENTS

I would like to take this opportunity to show appreciation to advisors, colleagues, and friends who were vital to the completion of this study. First, my immediate advisors, Dr. Hearn from the University of Windsor and Mr. Dale Wannamaker formerly from Prestressed Systems Incorporated, thank you for your time and patience you gave me through the entirety of this project. Secondly, I thank the staff at Prestressed Systems Incorporated, from the president, Mr. Loris Collavino who gave me the opportunity to both work and study at PSI, to the labourers in the plant who took care to work around the testing equipment, thank you. Special thanks go to the Quality Control Personnel who were a great assistance in the implementation of this work. I am also grateful to my closest confidant who constantly motivates me to strive for success in everything I do, my wife Carey.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

We live in a world of constant change. Something that seems irreplaceable today may become obsolete in ten years, one year, one month or even one week. Take computers for example. It seems as though the day you buy a new computer is the day it is superseded by a faster, more powerful one. To stay competitive one must accept change and learn how to use it to one's advantage.

The purpose of this study was to implement change, more specifically, to replace zero-slump concrete test cylinders used in the precast concrete industry to estimate concrete compressive strength, with a more reliable, efficient, and cost effective method, the Maturity Method. To gain a further understanding of the theory of maturity and how it may be utilized in the precast concrete industry and in particular the production of hollowcore slabs, the objectives of this investigation were to conduct:

1) an investigation of the methods and materials used to produce precast hollowcore slabs,
2) an evaluation of the practice of making, curing, and testing zero-slump concrete test cylinders,
3) a review of the history and theory of maturity to help understand the concept of cement hydration and how the Maturity Method may be altered to fit specific applications such as the production of hollowcore,
4) an experimental study to determine appropriate maturity functions for zero slump concrete, and

5) a correlation study of maturity versus compressive strength in order to calculate required maturity values that equate to specified hollowcore concrete compressive release strengths.

The results of the above objectives were used to implement the Maturity Method into the manufacture of hollowcore at Prestressed Systems Incorporated (PSI).

Also, a discussion is given on the evaluation of the Maturity Method as it is used in its intended function at PSI. Strand slippage data were used to measure the reliability and performance of the new method and the optimization of the hollowcore manufacturing process with respect to mix design, labour and accelerated curing energy that resulted are discussed.

2 BACKGROUND

2.1 INTRODUCTION

Before attempting to change a system, it must be fully understood first. In this section a look at the methods and materials used to create precast hollowcore is offered. The precast industry will be defined, the method of hollowcore production outlined, high performance concrete identified, hollowcore optimization introduced and hollowcore concrete compressive strength reviewed.

2.2 PRECAST CONCRETE

The term *precast concrete* refers to a specific type of construction that utilizes elemental, structural concrete building components. The components are manufactured at a precast concrete facility under controlled environments then transported and installed at sites in different geographical locations. The precast elements utilize prestressing tendons to increase and maintain adequate structural capacity. Advantages of a precast system include; controlled curing of the concrete (i.e. temperature and humidity), time and cost efficiency associated with short curing times and fast site installations (i.e. elimination of on-site formwork), and smaller member cross-sections and longer spans (i.e. reduction of dead load) (PSI 2002, PCI MNL 120-99, CPCI 1996).

2.3 HOLLOWCORE PRODUCTION

One of the most widely used precast elements is the 1.22 m (4 ft) wide hollowcore slab. A hollowcore slab is a structural, precast, prestressed concrete member with continuous hollow voids. These slabs have been effectively used as floor, roof and wall systems in residential, commercial, and institutional building construction whether they are steel, cast in place, or precast concrete framed structures. Hollowcore slabs are produced in precast manufacturing facilities by casting zero-slump concrete with high frequency, low amplitude power extruders to make slabs of various depths (PSI 2002, PCI MNL 120-99). A stack of hollowcore slabs is shown in Figure (1) and a typical application of hollowcore is shown in Figure (2).

Continuous production requires the hollowcore to be cast and removed within a limited time frame. The major factor controlling the time by which the hollowcore can be removed from the casting beds is the minimum concrete compressive release strength. The minimum release strength is the compressive strength that must be attained prior to detensioning in order to handle the prestress force applied when the steel tendons are cut, ensuring that there is adequate bond to resist slippage, as well as the forces associated with the stripping and handling of the individual slab (PCI MNL 116-99 *sec. 5.3.17*, CSA A23.4-00 *sec 26.2.7.2.1*).

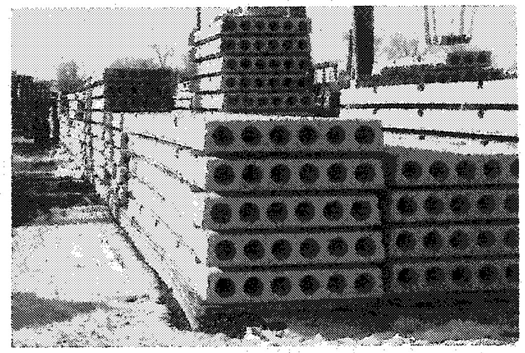


FIGURE 1: A STACK OF HOLLOWCORE SLABS IN STORAGE

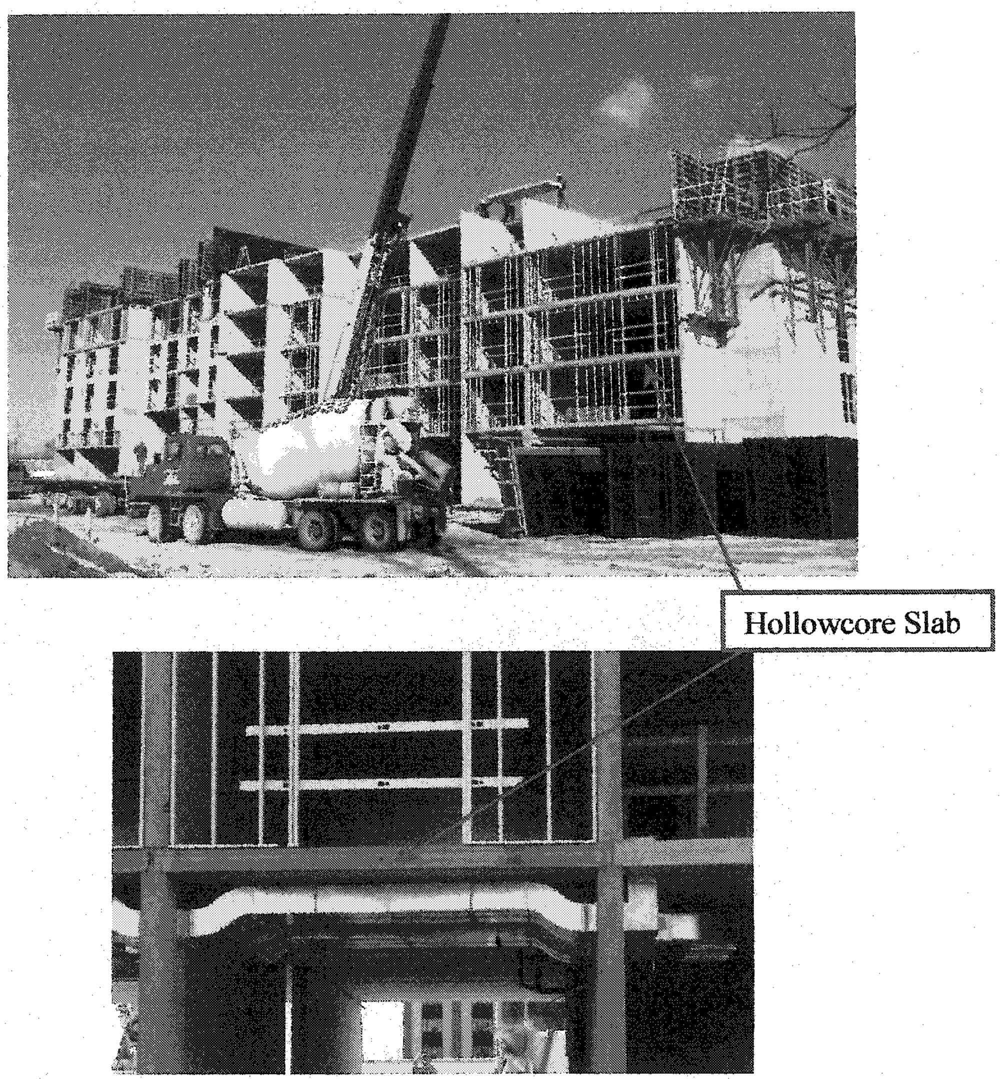


FIGURE 2: HOLLOWCORE IN A HOTEL APPLICATION

2.4 HIGH PERFORMANCE CONCRETE

The zero-slump concrete that is used in the production of hollowcore has no workability and has been termed concrete that is extremely dry and very stiff (Neville 1996), as well as being classified as a High Performance Concrete (HPC). HPC can be briefly described as concrete specially designed for a particular application (Delagrave 1997), in which normal Portland concrete could not perform. Generally, in this application HPC incorporates the following; high early cement (Type 30 Portland Cement), low water cement ratio (0.35 and less), supplementary cementing materials (fly-ash, slag, or silica fume), and various admixtures (superplasticizers, accelerators). The advantages of HPC may include rapid early age strength gain, high 28-day strength, improved durability, and extended service life.

2.5 ACCELERATED CURING

Accelerated curing techniques are employed in the precast industry to maintain a desired level of productivity. Heat treatment of concrete is used to accelerate its strength development, thus leading to a faster re-use of the casting beds. One type of accelerated curing technique normally applied to the production of hollowcore, is the radiant heat method that utilizes hot oil or steam pipes embedded under the casting bed (CSA A23.4-00 *sec. 21.2.2*).

2.6 HOLLOWCORE OPTIMIZATION

In order to maintain an efficient and cost effective operation, optimization must be considered at every step of production. In the manufacture of hollowcore, optimization with respect to cost is applied to three main areas. First, the concrete mix design in which the cementitious content must be minimized. Secondly, the labour needed to produce the desired number of hollowcore beds per day must be minimized. Thirdly, the accelerated curing cycle must be as energy efficient as possible. If there exists change that can positively affect either or all of the above areas of optimization it must be explored.

Since, reliability can be directly related to optimization, a study was initiated to evaluate the benefits of replacing the existing method used to measure concrete compressive release strength with a more reliable method.

2.7 COMPRESSIVE STRENGTH DETERMINATION

Acceptable methods for evaluating compressive strength of zero-slump concrete are outlined in the Canadian Standards Association (CSA) A23.4-00 (Precast Concrete – Materials and Construction) section 17.8.1. Commonly, in the precast industry compressive strength of hollowcore concrete is quantified by using concrete test cylinders. The method by which zero-slump test cylinders are made, cured, and tested should conform to the practice set out by the standard CSA A23.2-00 test number 12C. This method includes the use of a Modified Proctor Hammer to compact the concrete into steel molds to produce a specimen of the same density as the product represented. The molds are then placed at the head of the casting bed during the curing cycle and tested in compression prior to the tendon stress transfer stage.

The test procedure A23.2-12C is time consuming and it is questionable whether the specimens are actually representative of the extruded concrete, since cylinder compaction may be insufficient. The method of producing test cylinders of zero-slump concrete is shown in Figure (3) and a typical wet cast cylinder is compared to a typical zero-slump cylinder in Figure (4). There is a considerable difference between the two cylinders. The wet cast cylinder is smooth and uniform throughout while the ends of the zero-slump cylinder are visibly porous and non-uniform. Since, zero slump test cylinders have noticeably porous ends questions arise pertaining to the reliability of these cylinders especially during the compressive strength testing.

PSI believes that the porous ends of the cylinder lead to apparent low cylinder strengths. Cylinders that have porous ends usually fail because of chipped edges when tested for compressive strength. Such cylinders are practically useless in predicting the release strength of the hollowcore concrete for which they represent. Drilled cores are considered a good representation of the product because they are extracted from extruded concrete and therefore are used to determine 28-day strength. However, drilling cores to determine release strengths during the manufacturing process would be time consuming when time is of the essence.

The standard CSA A23.4-00 also states in section 17.8.2 that, "... other nondestructive testing, calibrated to a test specified in Clause 17.8.1 (drilled cores for example)," may be used to determine, "intermediate strength levels, such as handling or transfer of the prestress force..." Also, the Precast/Prestressed Concrete Institute (PCI) states in Division (6-2) of MNL-116-99 (Manual for Quality Control) that, "non-destructive testing may serve to determine stripping, transfer or shipping strengths ..."

There were a number of non-destructive test (NDT) methods that were considered when a replacement for the zero slump cylinder method was contemplated. To name a few; the Rebound Number Method (ASTM C805-97), the Pull-out Strength Method (ASTM C900-99), the Penetration Resistance Method (ASTM C803-98), and the Maturity Method (ASTM C1074-98).

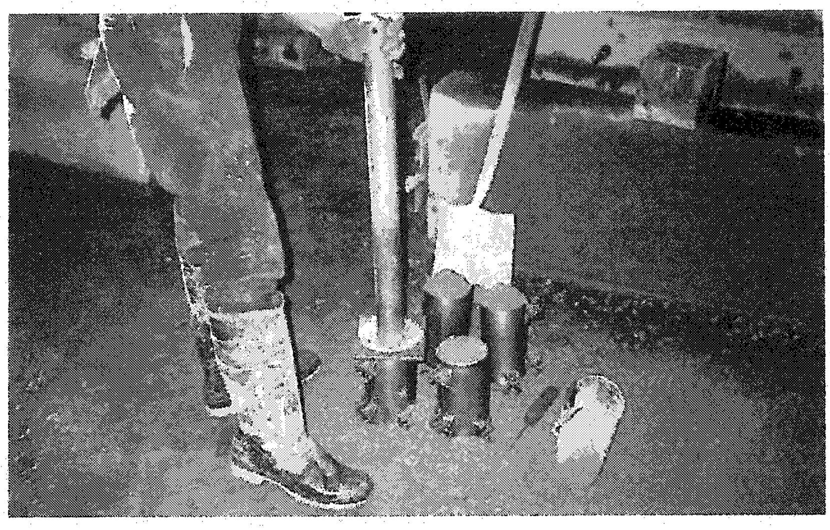


FIGURE 3: MODIFIED PROCTOR HAMMER BEING USED TO COMPACT ZERO SLUMP CONCRETE INTO STEEL MOLDS

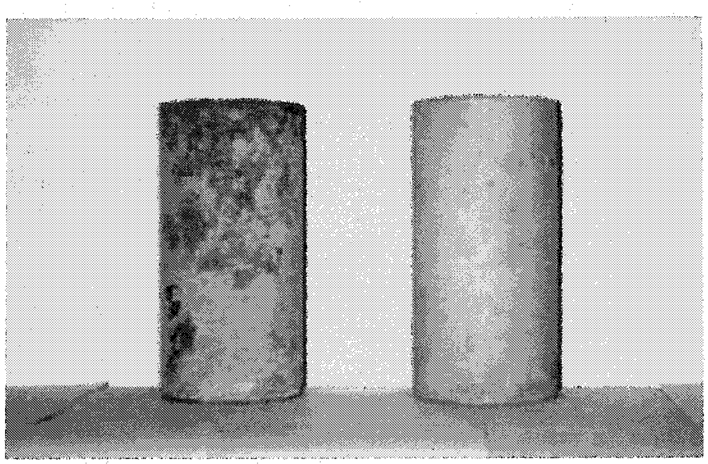


FIGURE 4: LEFT – A ZERO SLUMP TEST CYLINDER AFTER BEING STRIPPED OF THE MOLD
RIGHT – A WET CAST TEST CYLINDER AFTER BEING STRIPPED OF THE MOLD
NOTE; NOTICE THE IRREGULARITY AND VOIDS OF THE ZERO-SLUMP CYLINDER IN COMPARISON TO THE WET CAST CYLINDER

2.8 SELECTION OF A NON-DESTRUCTIVE TEST

The Rebound Number Method has been attempted in the hollowcore plant at PSI using Smidt Hammers, but resulted in very little success. The calibration procedure limited the use of the hammers and therefore no real confidence was gained. Since, it could not be established how the metal insert of the Pull-out Strength Method could be encased in the extruded zero-slump concrete this method was not pursued. An attempt at the Penetration Resistance Method was made on a few hollowcore slabs, however, it seemed that the degree of concrete compaction skewed the results and the method was dismissed.

The Maturity Method has been extensively studied since the 1950's and found to be applicable to HPC (Carino et al. 1992, Pinto and Hover 1996, Dong et al. 2002). The Maturity Method also had the potential to accurately estimate the compressive strength of hollowcore concrete at early ages. This would allow for mix design optimization by selecting the appropriate cementitious quantity for any required stripping time. Also, the measurement of strength during production could be real-time and ongoing. That would mean that the strength development could be determined at any time and extrapolations could be made, thus optimization could potentially be improved in the scheduling of the labour force. Furthermore, since the Maturity Method is a temperature based system, it had the potential to communicate with the heating system for continuous energy optimization. Therefore, the Maturity Method was explored as the replacement.

3 LITERATURE REVIEW OF MATURITY

3.1 INTRODUCTION

The Maturity Method has been suggested as a replacement for the zero-slump cylinder method. The Maturity Method is a non-destructive test that has the potential to more reliably estimate early age compressive strength of hollowcore concrete, save the Quality Control Department time and aid in the optimization of the manufacturing process of hollowcore.

In this section, the development of the maturity theory through history will be outlined to give a better understanding of the concept, how it has been used in the past as well as how it may be utilized in the precast concrete industry of today.

3.2 EMPIRICAL MATURITY FUNCTION

According to Adam Neville, "The fact that the strength of concrete increases with the progress of hydration of cement, coupled with the fact that the rate of hydration of cement increases with an increase in temperature, leads to the proposition that strength can be expressed as a function of the time-temperature combination," (Neville 1996). This premise was first developed in the early 1950's when an approach was proposed to account for the combined effects of time and temperature on the strength development of concrete. It was postulated that a single numerical value could be computed from a measured temperature history during a curing period and the value could be related to the concrete compressive strength. This value was called **Maturity** by A. G. Saul who created the maturity rule, "Concrete of the same mix at the same maturity has approximately the same strength whatever the combination of temperature and time go to make up that maturity," (Saul 1951, Carino 1984, Malhotra and Carino 1991).

3.2.1 TEMPERATURE-TIME FACTOR

Around 1950, after reviewing earlier work by McIntosh and Nurse, Saul was able to quantify maturity (McIntosh 1949, Nurse 1949, Malhotra and Carino 1991). He was able to link maturity to the product of time and temperature with the simple mathematical relation; the sum of the time interval multiplied by temperature during that interval is called maturity index and correspond to the area between the temperature-time curve and the datum temperature line where strength gain ceases (assumed to be -10 °C) as shown in Figure (5).

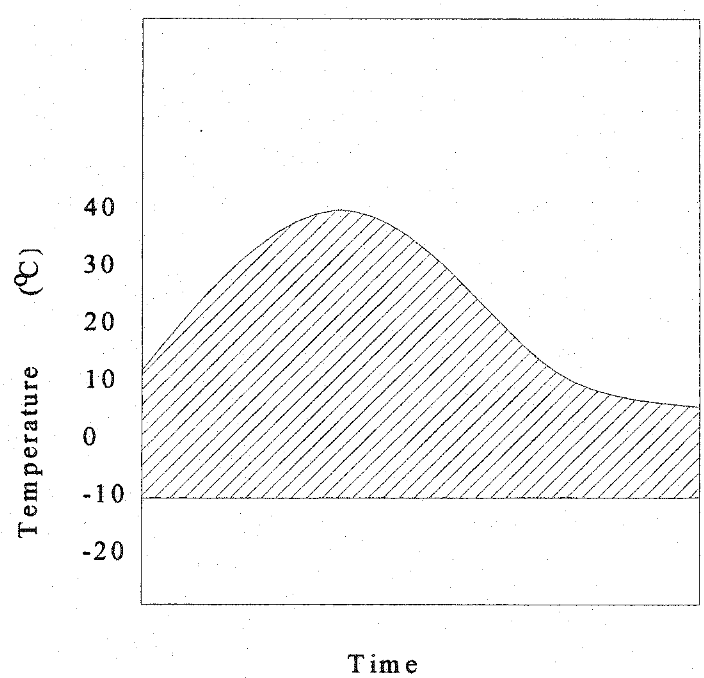


FIGURE 5: A TYPICAL TEMPERATURE HISTORY

Maturity M is calculated using the traditional relation,

$$\boldsymbol{M = \int (T-T_o)dt} \tag{1}$$

where, T is the temperature of the concrete and T_o is the datum temperature below which hydration ceases with time t. After integration,

$$\boldsymbol{M = \sum (T-T_o)\, \Delta t} \tag{2}$$

Equation (2) has become known as the Nurse-Saul function (Carino 1982, Carino 1984, Tank and Carino 1991, Malhotra and Carino 1991, Carino et al. 1992, Kjellsen and Detwiller 1993, Pinto and Hover 1996) and recognized by ASTM C 1074 as the *temperature-time factor*.

3.3 THEORETICAL MATURITY FUNCTIONS

A theoretical derivation of the *temperature-time factor* function is given here and was originally presented by Bernhardt in 1956 and summarized by Carino and Malholtra (Bernhardt 1956, Carino 1984, Malhotra and Carino 1991).

The rate of strength gain dS/dt at any age t, is assumed to be a function of the current strength S and the concrete temperature T, written as,

$$\boldsymbol{dS/dt = f(S) \bullet k(T)} \tag{3}$$

where $f(S)$ is a function of strength and $k(T)$ is a function of temperature. Bernhardt used the following empirical function,

$$f(S) = S_u \, [1 - (S / S_u)]^2 \tag{4}$$

where S_u is the limiting or ultimate strength at infinite age.

If we assume S_u is independent of curing temperature, Equation (3) and (4) are combined,

$$\int_0^S dS / [1 - (S / S_u)]^2 = S_u \int_{t_o}^{t} k(T) \, dt \tag{5}$$

where, t_o is the age at the start of strength development and usually called initial set.

The general form of the maturity function is the integral on the right side of Equation (5) and will be called $M(t,T)$,

$$M(t,T) = \int_{t_o}^{t} k(T) \, dt \tag{6}$$

By integrating the left side of Equation (5) and rearranging,

$$S = S_u \, \{ M(t,T) / [1 + M(t,T)] \} \tag{7}$$

3.3.1 ISOTHERMAL CURING

For the special case of isothermal curing conditions, the maturity function becomes,

$$M(t,T) = k \, (t - t_o) \tag{8}$$

and Equation (7) becomes Equation (A1.1) of ASTM C 1074,

$$S = S_u \{k\,(t\text{-}t_o) / [1 + k\,(t\text{-}t_o)]\} \qquad (9)$$

where k is the value of the temperature function, or rate constant, at the concrete temperature T. Figure (6) is a plot of Equation (9) that shows the curve is a hyperbola with $(k \bullet S_u)$ as the initial slope at t_o and is asymptotic to the limiting strength S_u. The parameters S_u, k, and t_o are mix-specific and are obtained by least-squares curve fitting Equation (9) to a given set of strength-age data.

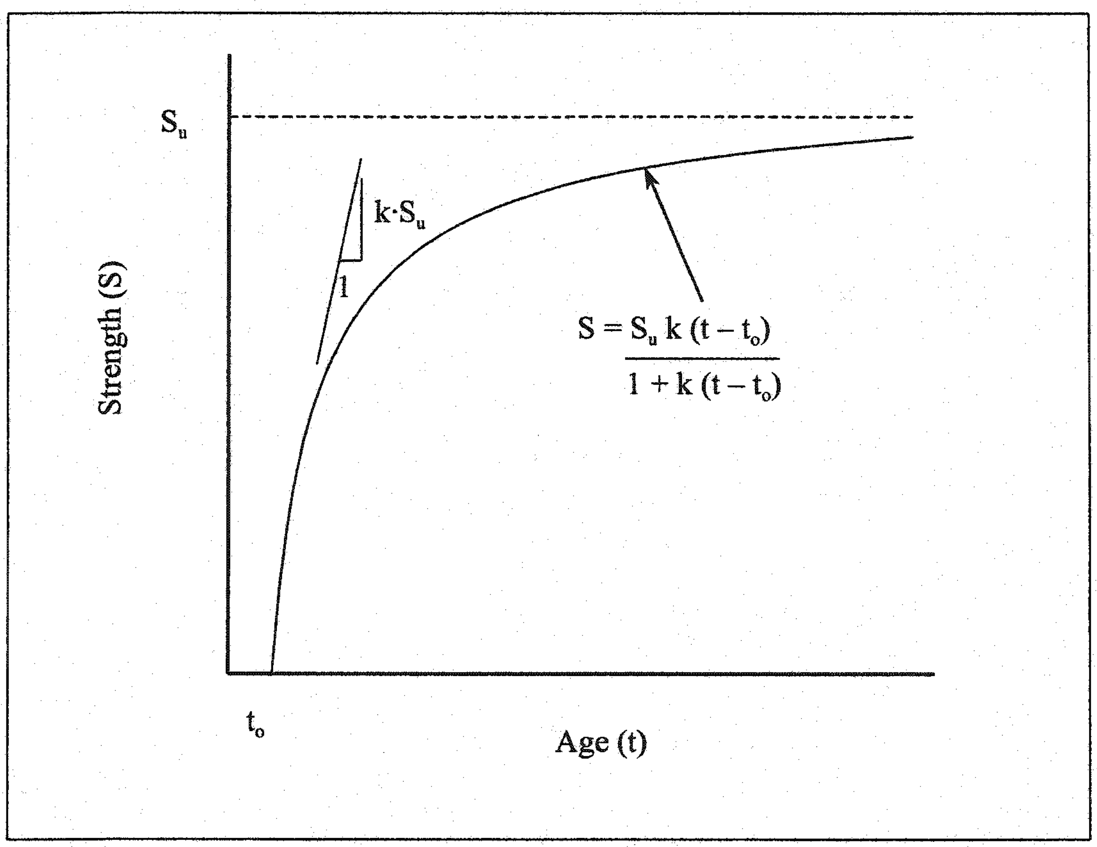


FIGURE 6: HYPERBOLIC EQUATION FIT TO STRENGTH-AGE RELATIONSHIP - TAKEN FROM (CARINO 1984)

Examples of the use of Equation (9) can be found in (Carino 1984, Tank and Carino 1991, Carino and Tank 1992, Carino et al. 1992). Furthermore, a parabolic-hyperbolic function, Equation (10), was suggested by Geiker and Knudsen and found to fit the data well in previous experiments (Geiker 1983, Knudsen 1984, Carino et al. 1992),

$$S = S_u \{[k\ (t-t_o)]^{1/2}\} / \{1 + [k\ (t-t_o)]^{1/2}\} \tag{10}$$

The parabolic-hyperbolic function was found to fit the strength development of concrete with a high rate of initial strength development. Also, it produced a hyperbola with a higher value of limiting strength.

3.3.2 VARIABLE TEMPERATURE CURING

Since most concrete in the field or industry is not isothermally cured, strength development under variable temperature conditions is reviewed. Since the temperature function $k(T)$ is no longer constant, its temperature dependency must be evaluated. Assuming the simple case of a linear relationship,

$$k(T) = A(T-T_o) \tag{11}$$

where T_o is the temperature at zero rate constant and A is the slope of the straight line.

The maturity function is now written as,

$$M(t,T) = A \int_{t_o}^{t} (T-T_o)\ dt \tag{12}$$

We can see now the similarity between this equation and the *temperature-time factor* and understand that the fundamental assumption was a linear relationship between rate constant and temperature.

If maturity is given as,

$$M = \int_0^t (T-T_o)\, dt \tag{13}$$

$$M_o = \int_0^{t_o} (T-T_o)\, dt \tag{14}$$

where, M is the maturity at age t and M_o is the maturity at age t_o, the general maturity function Equation (7) becomes,

$$S = S_u \{ A\,(M-M_o) / [1 + A\,(M-M_o)] \} \tag{15}$$

Values of maturity index using Equation (2) can be calculated and plotted against compressive strength data for any given mix to obtain a compressive strength-maturity relationship as shown in Figure (7). Saul believed there existed a unique strength-maturity curve for each mix cured within any temperature time regime (Saul 1951).

However, in 1956 McIntosh noted that specimens exposed to high early age temperature would be weaker than specimens exposed to low early age temperature of the same mix and maturity index (McIntosh 1956). Klieger also reported that initial curing temperature influenced the shape of the strength-maturity relationship, as explained graphically in Figure (8) (Klieger 1958, Malhotra and Carino 1991).

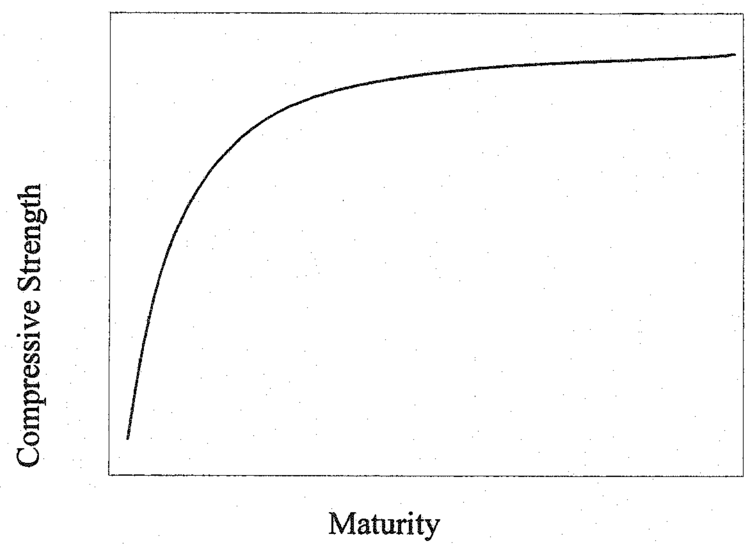


FIGURE 7: CONCRETE STRENGTH MATURITY RELATIONSHIP

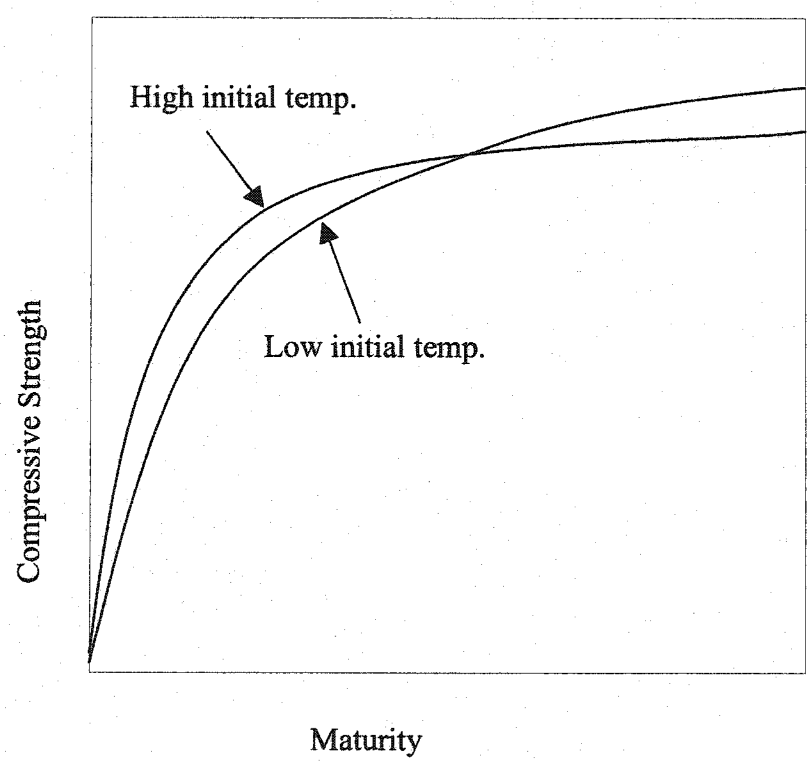


FIGURE 8: CONCRETE STRENGTH MATURITY RELATIONSHIP – VARYING INITIAL TEMPERATURE

Verbeck and Helmuth explained that a rapid initial hydration produces products that are not as structured within the pores of the hardened cement paste. Also, shells of low permeable hydration products form around the cement grains. The poorer structure of hydration products lead to more large pores which reduce strength. The shells also impede hydration of the unhydrated cement grains at later ages (Verbeck and Helmuth 1968, Malhotra and Carino 1991).

Another theory suggests that when fresh concrete is heated, its individual components such as hydrating cement, aggregate, water, and air, undergo differential expansions due to different coefficients of thermal expansion. These varying rates of expansion lead to internal forces, which could cause microcracking and reduce the long-term strength when compared to companion concrete not exposed to a high initial curing temperature (Pfeifer and Marusin 1981).

3.3.3 RELATIVE STRENGTH VERSUS MATURITY

A major assumption of Equation (15) was that S_u was independent of curing temperature. It has now been shown that this is untrue and a unique strength-maturity relationship for a given concrete does not exist. However, Carino suggested by normalizing the data (dividing S values by S_u) a unique relative strength versus maturity function would exist and take the following form (Carino 1984),

$$S / S_u = A\,(M\text{-}M_o) / [1 + A\,(M\text{-}M_o)] \qquad \textbf{(16)}$$

and the parabolic-hyperbolic form would be,

$$S / S_u = [A\,(M-M_o)]^{1/2} / \{1 + [A(M-M_o)]^{1/2}\} \qquad (17)$$

Then if we take $\propto$ as the desired value of S/S_u for the linear hyperbolic model we get,

$$M = M_o + [\propto / A\,(1 - \propto)] \qquad (18)$$

and for the parabolic-hyperbolic model we have,

$$M = M_o + [\propto^2 / A\,(1 - \propto)^2] \qquad (19)$$

The new relations for modeling maturity versus strength, that allow for varying early age temperature effects, leads to a modified maturity rule; "Samples of a given concrete mixture which have the same *maturity* and which have had a sufficient supply of moisture for hydration will have developed equal fractions of their limiting strength irrespective of their actual temperature histories," (Malhotra and Carino 1991).

It should be noted that the modified maturity rule specifies that there must be a sufficient supply of moisture for hydration. If hydration were to stop because of a lack of moisture on a concrete product that was being monitored for maturity, the value of maturity that would be calculated on that particular product would be incorrect. Since, the Maturity Method only measures concrete temperature, if the hydration reaction stops, strength gain ceases but the temperature may still rise which would give false values of maturity index.

Also, it needs to be noted that the accuracy of Equation (16) and (17) depends on the validity of Equation (11) that states the rate constant varies linearly with curing temperature which may or may not be true. The relationship between rate constant and temperature will have to be evaluated through experiment using similar mix proportions as the concrete to be studied. However, one model that has been widely used for a non-linear relationship between rate constant and curing temperature is *equivalent age* presented in the next section (Carino 1984, Malholtra and Carino 1991, Carino et al. 1991).

3.3.4 EQUIVALENT AGE

It was suggested in 1960 by Verbeck that since cement hydration is an exothermic reaction, the rate of hydration obeys the Arrhenius equation that has been historically used to describe the rate constants of chemical reactions (Copeland et al. 1962, Carino et al. 1992),

$$k(T) = B\, e^{-(E/RT)} \tag{20}$$

where,

k = rate constant
B = constant - frequency factor related to the frequency of molecular collisions
E = activation energy
R = universal gas constant
T = absolute temperature in degrees Kelvin.

Now the maturity function can be approximated from the concrete thermal history by,

$$M(t,T) = \sum_{t_0}^{t} k \bullet \Delta t \tag{21}$$

where k is the rate constant during the time interval Δt (Carino 1984).

Freiesleben-Hansen and Pederson suggested an improved function based on the above called *equivalent age* for computing maturity index in 1977 (Freiesleben-Hansen and Pederson 1977, Carino et al. 1992). *Equivalent age* represents the duration of the curing period at the reference temperature that would result in the same relative strength gain as the curing period at other temperatures, thus,

$$k_r \bullet t_e = \sum k \bullet \Delta t \tag{22}$$

where, k_r is the rate constant at the reference temperature and t_e is equivalent age. Solving for t_e, we get the *equivalent age* maturity function as suggested (Freiesleben-Hansen and Pederson 1977, Carino et al. 1992) and recognized by ASTM C 1074 in the form,

$$t_e = \sum (k/k_r)\ \Delta t \tag{23}$$

from which,

$$t_e = \sum (Be^{-E/RT}/Be^{-E/RT_r})\ \Delta t \tag{24}$$

and

$$t_e = \sum e^{-E/R(1/T_a - 1/T_r)}\ \Delta t \tag{25}$$

where, T_a is the average absolute temperature of the concrete during time interval Δt and T_r is the absolute reference temperature.

3.4 SUMMARY

Up to this point the two alternative maturity functions, *temperature-time factor* and *equivalent age,* as suggested by ASTM C 1074 have been reviewed. Both, the *temperature-time factor*, Equation (2), and the *equivalent age*, Equation (25), have been used in other studies as maturity functions to calculate maturity index of a given concrete from its temperature history. The most appropriate maturity function should be determined through experiment with samples of concrete similar to that, which is to be evaluated with maturity and compressive strength estimations made.

By isothermally curing concrete samples at different temperatures, plots of strength versus age can be obtained. A linear hyperbolic, Equation (9) or a parabolic-hyperbolic, Equation (10) function can be curve fit to the data with a computer program and the rate constants at each temperature can be determined from the regression analysis. Then a plot of rate constant versus temperature can be created and used to decide if there is a linear or non-linear relationship between rate constant and temperature which then enables the user to:

1) choose which maturity function to use, *temperature-time factor* or *equivalent age*, and
2) evaluate the mix-specific parameters of that chosen maturity function, datum temperature, T_o, for *temperature-time factor* or activation energy, E, for *equivalent age*.

A plot of relative strength versus *temperature-time factor* or *equivalent age* can be created to determine the applicability of the maturity method to the particular mix design being evaluated. If there exists a unique curve through the points, the maturity method is applicable. If at this point the user has a unique relative strength-maturity curve for their mix design, that curve can be solved using Equation (19) to give values of required maturity that correspond to any desired value of compressive strength.

3.5 NEED FOR RESEARCH

As discussed in Section (2.6), optimization of the production process of hollowcore was the motivation for this study. In order to achieve the maximum optimization, the highest degree of reliability in measuring compressive strength at release was sought. Two main areas of research needed to be expanded in this study that were not covered in the previous research of (Carino et al. 1983, Carino 1984, Aziz 1990, Carino and Tank 1991, Tank and Carino 1992, Carino et al. 1992, Dong et al. 2002).

First, the age at which the strength of hollowcore needs to be estimated is about 6 hours. The previous studies have not tested as such an early age. Secondly, the maximum curing temperature of the previous studies did not reach the 60 – 65 °C that is typically used to cure hollowcore. Furthermore, the combination of raw materials used to manufacture hollowcore such as cement type and manufacturer, aggregate types, admixture type and dosage, and water to cement ratio was not used in any of the other cited studies.

Therefore, to achieve the highest possible degree of reliability an experimental study was initiated to satisfy the following objectives:

1) evaluate the relationship between rate constant and curing temperature over the temperature range of 20 to 65 °C,
2) determine the most appropriate maturity function for each mix design, and
3) calculate the parameters of the maturity function that gives the best results.

4 EXPERIMENTAL PROCEDURE AND RESULTS

4.1 INTRODUCTION

Normally the designer of a prestressed concrete slab or beam will specify the minimum concrete compressive strength that is required before the prestressing force can be transferred from the tendons into the slab, beam or in the case of hollowcore, an entire bed. If one wanted to estimate that strength with the Maturity Method a correlation study would be required. That was precisely the goal of this experimental study and the objectives included the following:

1) select an applicable maturity function, *temperature-time factor*, Equation (2) or *equivalent age*, Equation (7),
2) determine the parameters of the function (datum temperature or activation energy),
3) develop strength versus maturity relationships for each mix design used in hollowcore production and model them with an appropriate equation, and
4) calculate required maturity that equates to specified concrete compressive release strengths.

Fortunately a standard practice was available and this study used the guidelines set forth in the American Society for Testing and Material's (ASTM) "Standard Practice for Estimating Concrete Strength by the Maturity Method," C 1074. Some modifications to the standard which had to be made are outlined throughout subsequent sections.

4.2 CONCRETE MIXES

The four most common zero slump concrete mix designs used for all sizes, 152, 203, 254, 305, and 356 mm (6, 8, 10, 12 and 14 inch) depth of hollowcore were chosen. The only difference among the mixes is the combination of cementitious materials that are changed to accommodate stripping times. Table (1) outlines the four mixes. The cementitious components listed are in quantities for one batch of 1.53 m^3 (2 yd^3). Complete mix design details can be found in Appendix (A).

TABLE 1: CEMENTITIOUS QUANTITIES FOR THE MIX DESIGNS

Mix Design	Type 30 kg (lbs)	Type 10 kg (lbs)	Fly Ash kg (lbs)
A	590 (1300)		
B	544 (1200)		
C	136 (300)	408 (900)	
D	136 (300)	318 (700)	91 (200)

1 kg = 2.204 lbs 1 m^3 = 1.31 yd^3

4.3 RATE CONSTANT VERSUS TEMPERATURE

To determine how the rate constant of the hydration of the cement varies with curing temperature and ultimately decide which maturity function to use, ANNEX (A1) of ASTM C 1074 was followed for this testing with any deviations being noted.

The standard C 1074 suggests using mortar cubes having a fine aggregate-to-cement ratio (by mass) that is the same as the coarse aggregate-to-cement ratio of the concrete mixture under investigation. Since mortar of such a mixture for zero slump concrete could not be effectively compacted into molds, it was decided to use actual concrete samples for this testing.

Samples of concrete from 203 mm (8 inch) hollowcore were extracted during normal production immediately after being extruded. The samples were in the form of 254 mm (10 inch) long elements as shown in Figures (9) and (10). Mixes B and D were chosen because there were the only two of the four mixes being used in the plant at that time. Also, it was a hypothesis, to be evaluated later, that the variation of rate constant with curing temperature would be similar for all four mixes (A, B, C, and D) since they all had similar raw material make-up and water to cement ratios. Equal numbers of samples were placed into three different curing baths once they achieved enough stiffness to keep them from falling apart, usually at an age of one and a half hours. The baths were heated, covered, saturated with lime and the temperature monitored with a thermocouple.

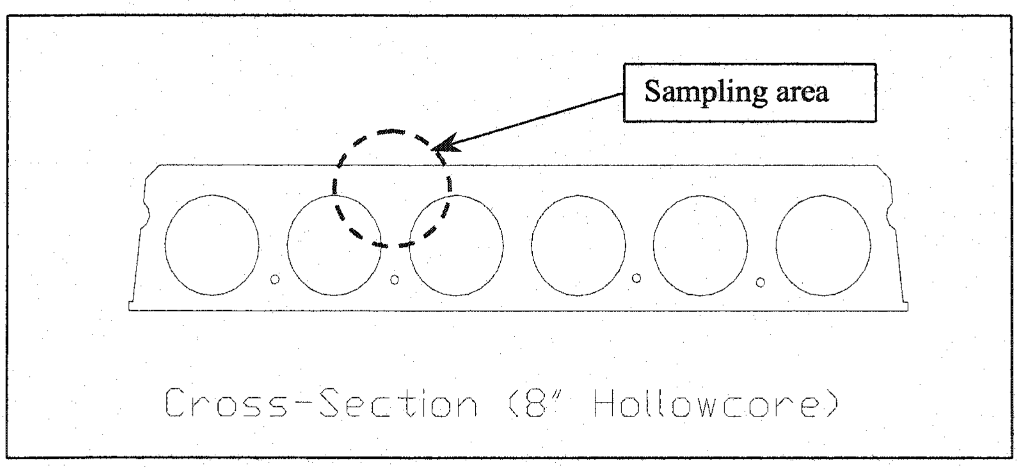


FIGURE 9: SAMPLING AREA SHOWN ON HOLLOWCORE CROSS-SECTION

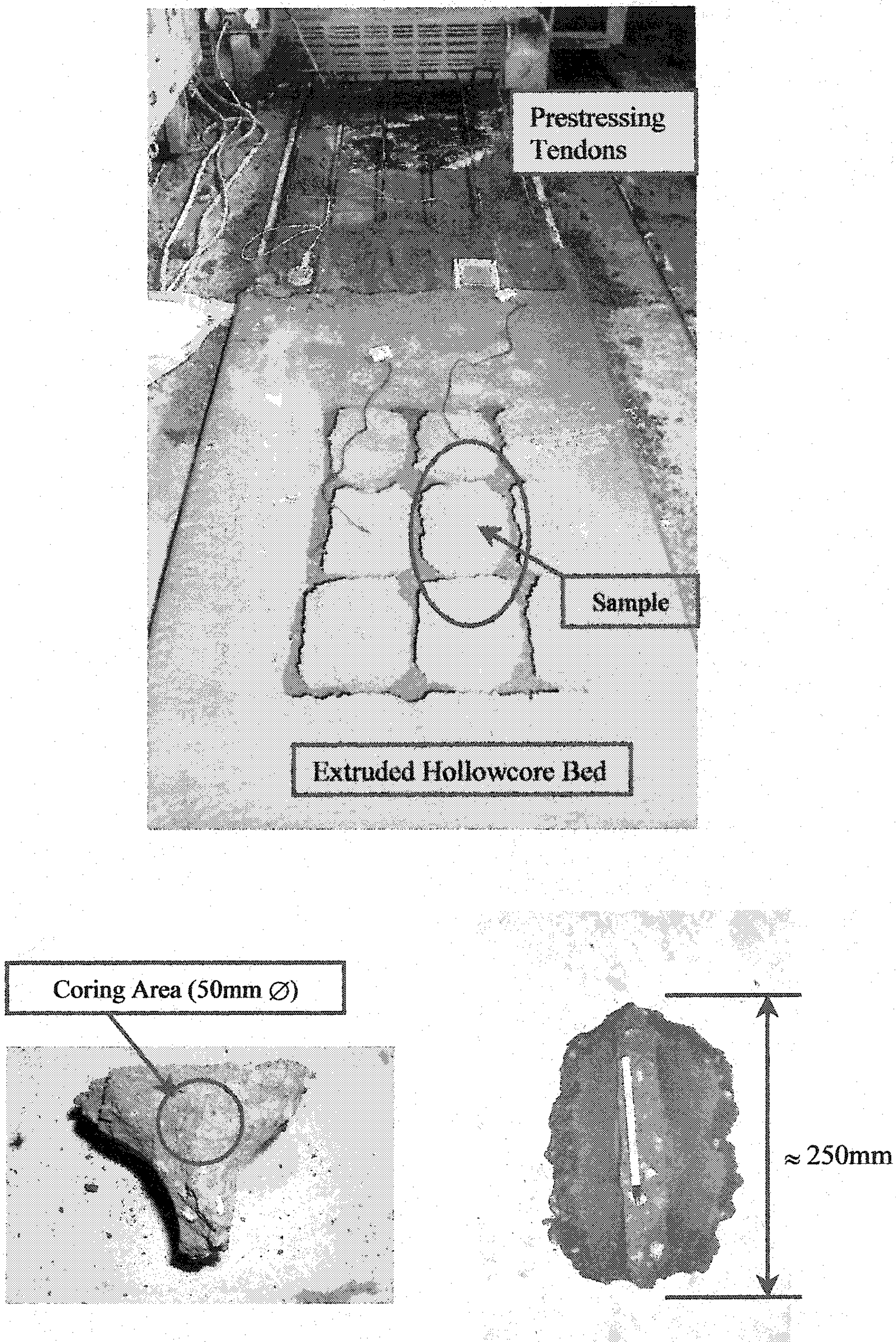


FIGURE 10: PHOTOGRAPH OF A TYPICAL SAMPLE USED – (TOP) CHISELED SAMPLES ON BED, (BOTTOM LEFT) END VIEW OF SAMPLE, (BOTTOM RIGHT) BOTTOM VIEW OF SAMPLE

All baths were held at constant temperature (isothermal curing), one at the minimum expected hollowcore curing temperature of 20 °C, one at the maximum expected curing temperature of 65 °C, and one mid way between the extremes, 40 °C.

ASTM suggests testing the first specimen at an age of two times the final set time and the remaining at twice the age of the previous test. In this experiment the strength is to be estimated within the first 12 hours of accelerated curing, therefore it was desirable to obtain a larger number of data points at the earlier ages than at the later ages. Seven-day and 28-day ages are considered an industry standard so they were chosen to remain consistent with standards, specifications and previous studies. In this experiment, specified ages of approximately 5, 8, 12, 24, 72 (3), 168 (7), and 672 hours (28 days), were used. The largest cylindrical specimen that can be obtained from a cross-section of hollowcore is 51 mm (2 inch) due to the geometric limitations. The standard CSA A23.2-00 test 14C and ASTM C 42 specify that the minimum core diameter shall be at least three times the nominal maximum coarse aggregate size. In this case the aggregate used is 16 mm (5/8 inch) and multiplied by three would give a minimum core diameter of 48 mm (1-7/8 inch). Therefore, a 51 mm (2 inch) core specimen would be appropriate.

The samples were cored to a size of 51 mm (2 inch) diameter using a standard Hilti core drill machine with the sample clamped to a piece of angle iron welded to the floor, see Figure (11). Each sample was cut, using a wet table ceramic tile saw, to 102 mm (4 inch) lengths in order to maintain a 2 to 1, length to diameter ratio and provide clean, square ends. The specimens were measured for dimension and weighed for density. At least three specimens were tested in compression at each test age and from each curing bath (9 specimens at each test age). The compression machine used was an

ELE CT 7500 compression tester for which a calibration report can be found in Appendix (B). An unbonded capping system as per ASTM C 1231 was used for all compressive strength tests. Steel caps with neoprene pads of 60 durometer were used for the early age tests and 70 durometer pads were used for strengths greater that 34 MPa (5000 psi). Further reading of the effect of using an unbonded capping system can be found in (Carrasquillo and Carrasquillo 1988). A typical test specimen and the compression test apparatus are shown in Figures (12) and (13).

The average strength versus age data were plotted with a program called KaleidaGraph. Equation (9) which is Equation (A1.1) *"*$S=S_u\, k(t-t_o)/(1+k(t-t_o))$*,"* from ASTM C 1074, was curve fit, where S is the compressive strength (MPa), S_u is the ultimate compressive strength (MPa), k is the rate constant (hr^{-1}), t is the test age (hr), and t_o is the age when strength development is assumed to begin (hr) (KeleidaGraph 2000). The plot for Mix D tested on March 1, 2001 is shown in Figure (14). The constants k, S_u and t_o were obtained from the best-fit regression analysis and the tabulated data and other plots can be found in Appendix (C).

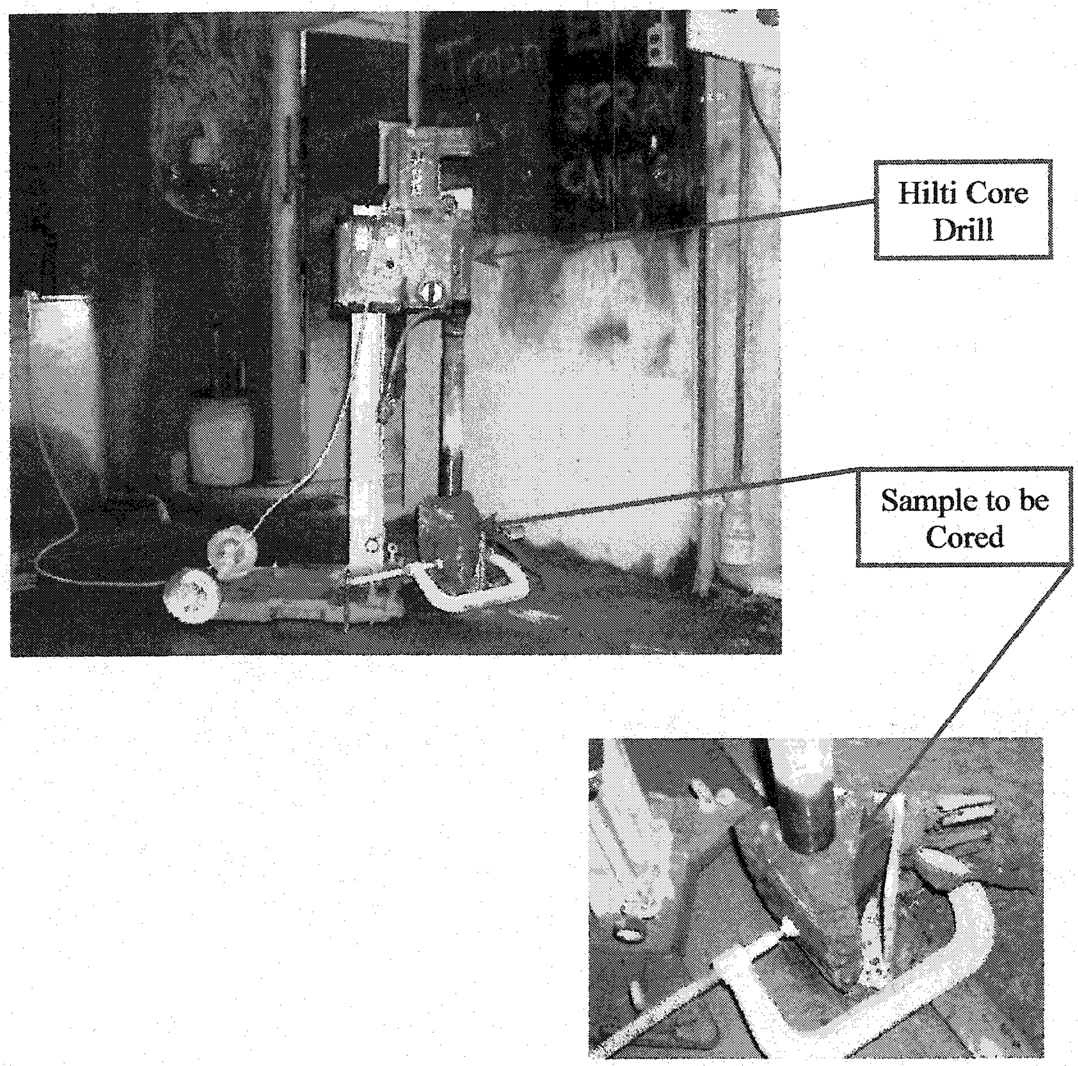


FIGURE 11: PHOTOGRAPH OF A CORING APPARATUS

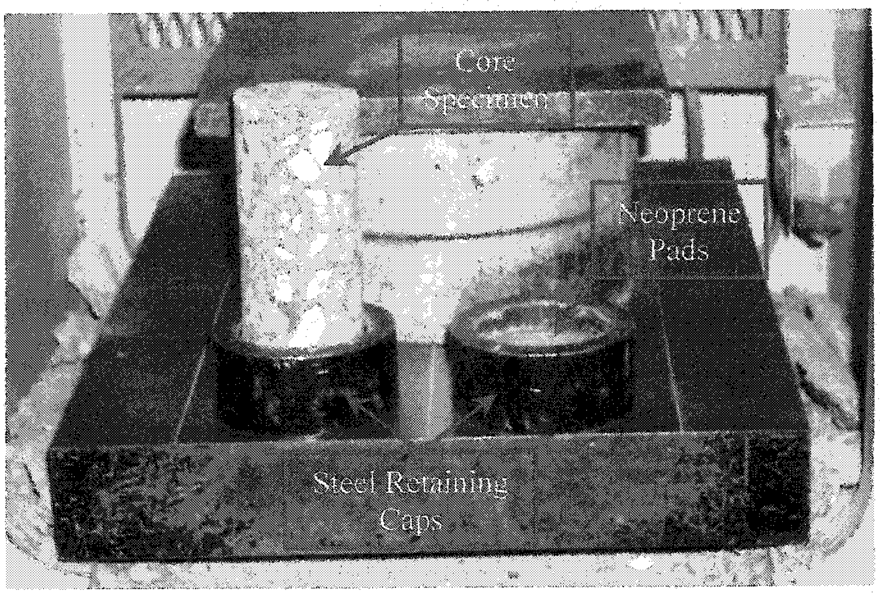


FIGURE 12: PHOTOGRAPH OF A TYPICAL CORE SPECIMEN

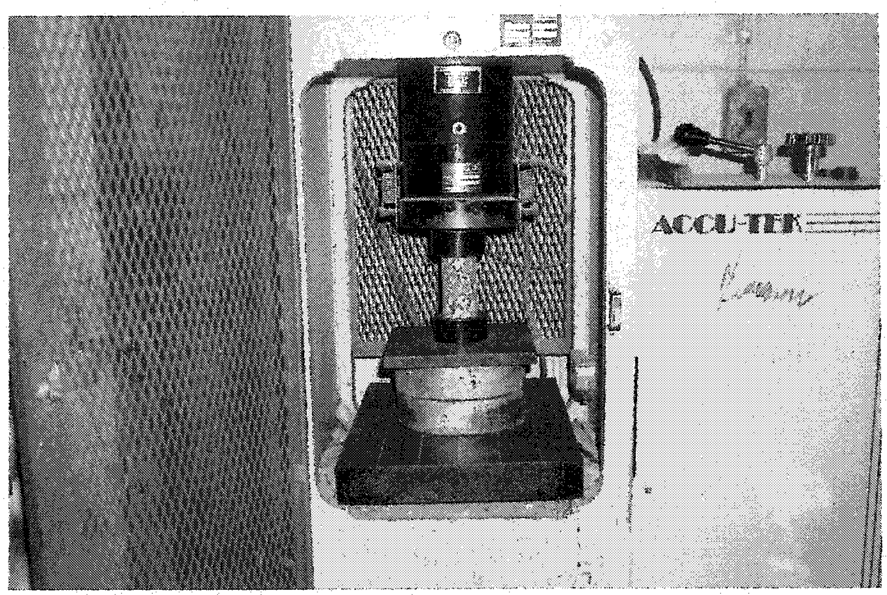
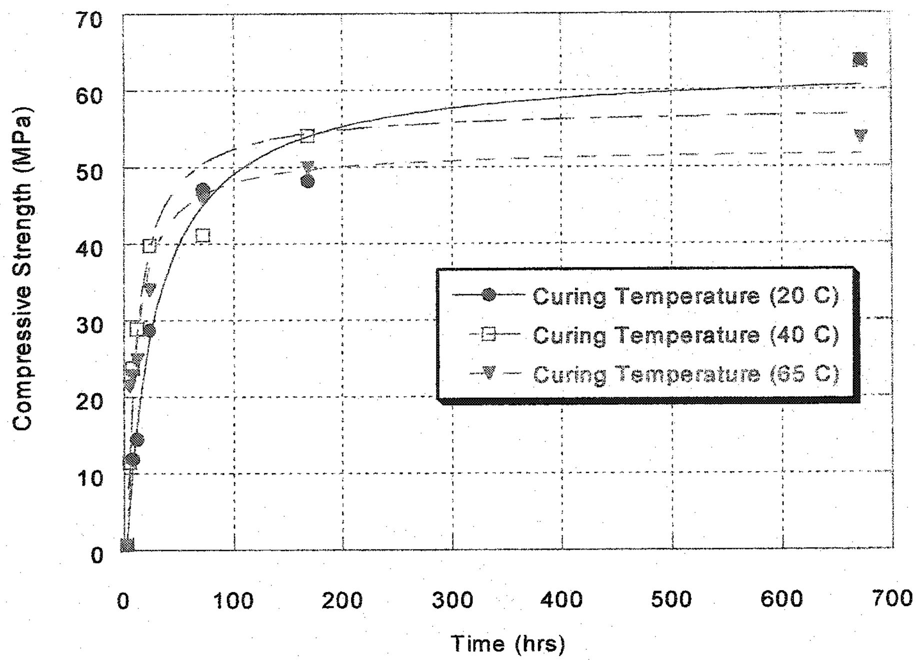


FIGURE 13: PHOTOGRAPH OF THE COMPRESSION TESTING APPARATUS



$S=S_u k(t-t_o)/(1+k(t-t_o))$		
65C	Value	Error
S_u	52.358	3.4208
k	0.11121	0.039364
t_o	1.8871	1.1263
Chisq	113.96	NA
R	0.97392	NA

$S=S_u k(t-t_o)/(1+k(t-t_o))$		
40C	Value	Error
S_u	57.603	3.9029
k	0.10201	0.034343
t_o	2.5948	0.94669
Chisq	147.7	NA
R	0.97596	NA

$S=S_u k(t-t_o)/(1+k(t-t_o))$		
20C	Value	Error
S_u	63.028	3.5408
k	0.035998	0.0089112
t_o	2.464	1.5287
Chisq	54.968	NA
R	0.99136	NA

FIGURE 14: STRENGTH VERSUS AGE FOR MIX D - MARCH 1, 2001

The values of rate constant k obtained from the regression analyses were plotted versus bath temperature for Mixes B and D as shown in Figures (15) and (16).

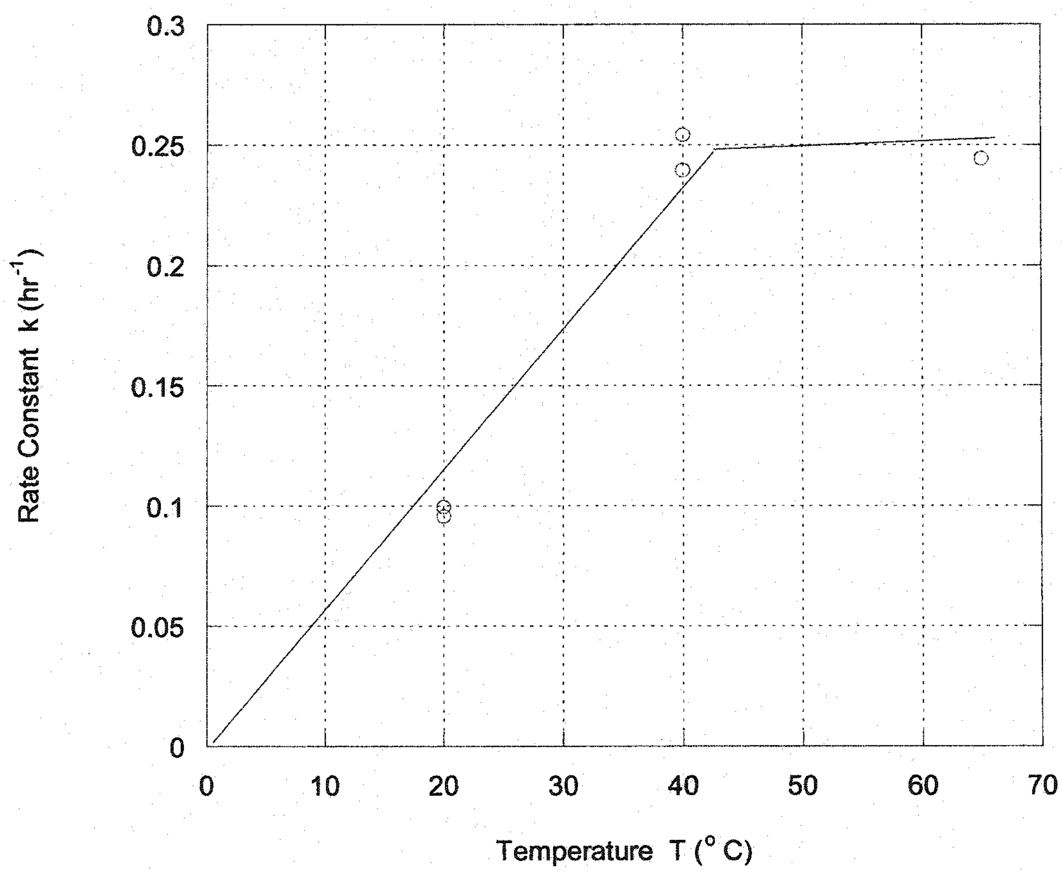


FIGURE 15: RATE CONSTANT VERSUS TEMPERATURE FOR MIX B - MARCH 20 & 22, 2001

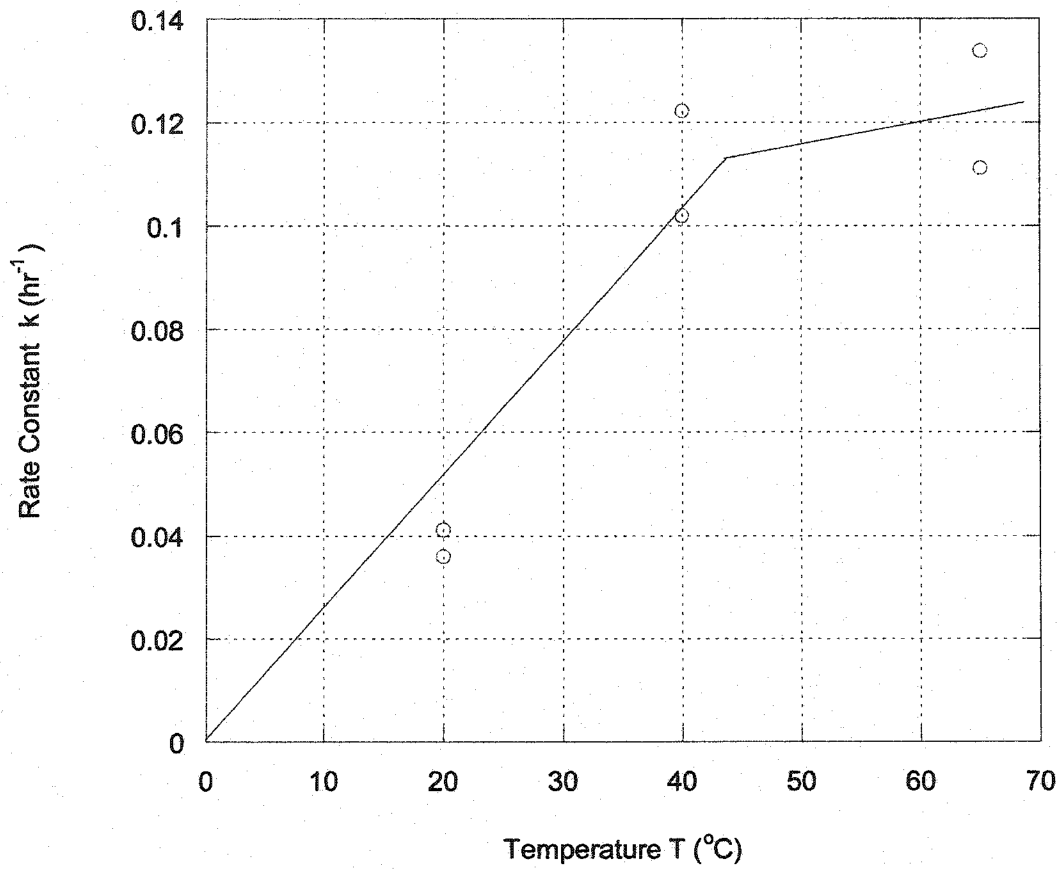


FIGURE 16: RATE CONSTANT VERSUS TEMPERATURE FOR MIX D – FEB 15 AND MAR 1, 2001

In all of the other research that was investigated a common trend was discovered. When concrete was cured, up to 40 °C, there was a distinct exponential relationship between curing temperature and rate constant (Carino 1984, Malhotra and Carino 1991, Tank and Carino 1991, Carino et al. 1992, Dong et al. 2002). This result then allows for the use of the *equivalent age* technique based on the Arrhenius equation.

By examining Figures (15) and (16) of this study it is not obvious if the rate constant has an exponential relationship with curing temperature through the range of temperatures used to cure hollowcore (20 to 65 °C). If we assume the results of this testing are concurrent with other studies and there is an exponential relationship between curing temperature and rate constant between 0 and 40 °C, there is insufficient data to evaluate what that relationship may look like. Furthermore, beyond 40 °C (uncharted territory) there seems to be a leveling off effect, which tells us that the rate constant for the hollowcore mixtures is reaching its maximum value between 40 and 65 °C.

By fitting a bi-linear relationship to the data, as was done in Malhotra and Carino 1991, we have decided for this testing to use the *temperature-time factor*, Equation (2) which is Equation (1) of ASTM C 1074 "$M(t) = \Sigma(T - T_o)\ \Delta t$," to calculate a maturity index.

4.4 MATURITY FUNCTION PARAMETERS

Now that a maturity function was chosen, the parameters of that function were required for each hollowcore mix design. The only constant or parameter needed for the *temperature-time factor* maturity function is the datum temperature.

Traditionally a datum temperature of -10 °C has been used, however it was shown that it may not be the best value to use (Carino 1984, Dong et al. 2002). Appendix (X1), section (X1.2) of ASTM C 1074 recommends a datum temperature of 0 °C for Type I cement with no admixtures cured between 0 and 40 °C. Knowing that hollowcore is produced with Type 30 (III) cement, a plasticizing admixture and cured between 20 and 65 °C, Figures (15) and (16) were used to determine an appropriate datum temperature. The first portion of the bi-linear curve yields a 0 °C datum temperature and that value was accepted for all four (A, B, C, and D) hollowcore mixes. Now, that a maturity function was chosen and the parameters of that function determined for the selected hollowcore mix designs, strength-maturity relationships were needed to estimate strength by measuring maturity.

4.5 STRENGTH MATURITY RELATIONSHIPS

Section (8) of ASTM C 1074 outlines the procedure for developing the Strength-Maturity Relationships. It specifies the preparation of a set of concrete cylinders for each mix design being modeled. Furthermore, the cylinders shall be moist cured at 23°C and tested at ages of 1, 3, 7, 14, and 28 days. Thermocouples embedded into at least two cylinders should be used to calculate maturity at each test age.

It was decided in this experiment to obtain a complete set of strength versus maturity relationships for all four hollowcore mixes as they are used under normal manufacturing conditions. The samples were chiseled but left on the beds this time to experience actual curing profiles as shown in Figure (10) just prior to tarping. Specimens were extracted, cored to 51 x 104 mm (2 x 4 inch) and tested at specified ages of 5, 6, 7, 12, 24 (1), 72 (3), 168 (7), and 672 hours (28 day). Furthermore, two samples were extracted immediately and cured under standard (23 °C) conditions for the entire 672 hours (referred to as S_{S28}) to determine what effect the high early age temperatures have on long term compressive strengths. For the most part four cores were averaged to determine the compressive strength at each test age. Thermocouples embedded into two samples on the bed were used to calculate maturity.

The complete set of results can be found in Appendix (D) and a summary of the 28-day compressive strength results is given in Table (2). As was expected the standard cured 28-day strengths S_{S28} were significantly higher than the 28-day strengths S_{28} of the specimens that were exposed to high early age temperatures, as shown in Figure (17). The strength reduction observed is concurrent with other studies (Pfiefer and Marusin 1981) and standards (CSA A23.4 – 00 *sec 17.5.2*). Values of reduced standard cured 28-day strength S_{S28R} were calculated using the correlation plot of Figure (17) and shown in Table (2) for future reference.

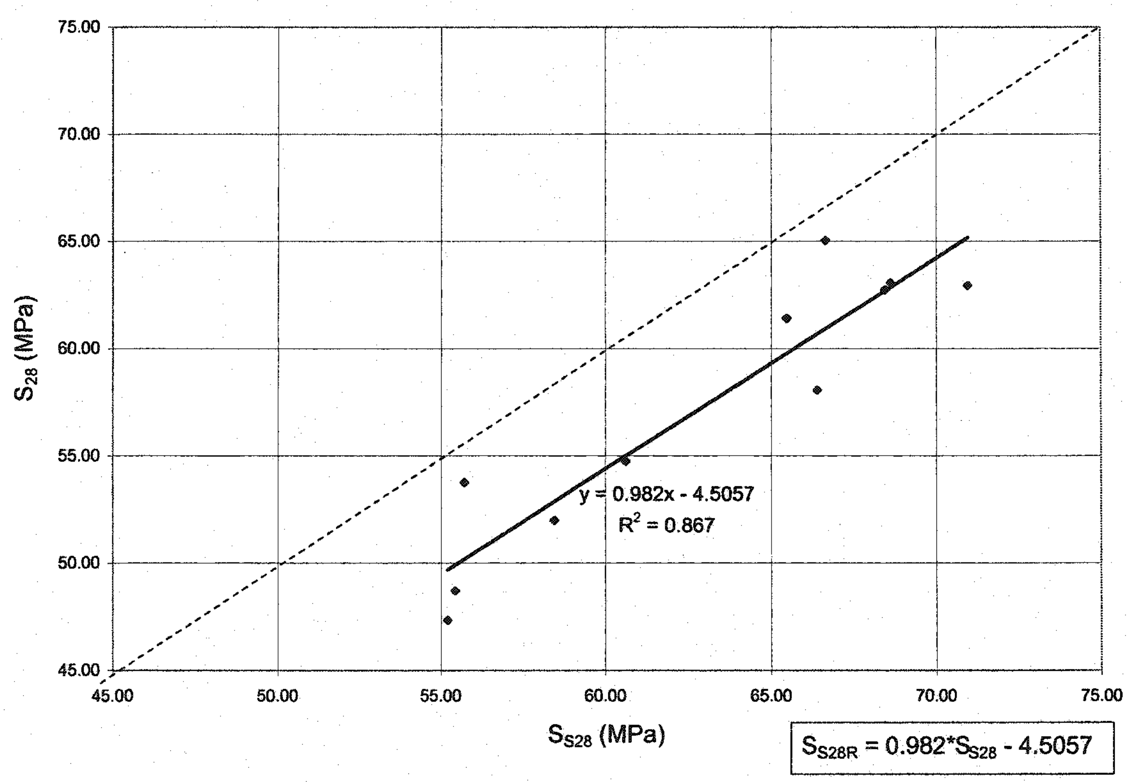


FIGURE 17: COMPRESSIVE STRENGTH CORRELATION – S_{S28} VS. S_{28}

The strength maturity results were plotted with KaleidaGraph and a Parabolic-Hyperbolic function, Equation (10), was fit to the data. A regression analysis was used to determine the limiting strength S_u for each trial of each mix. The strength versus maturity plots can be found in Appendix (C) and Figure (18) contains that for Trial #1 of Mix B. The limiting strengths for all mixes are given in Table (2).

TABLE 2: LIMITING STRENGTHS AND 28-DAY COMPRESSIVE STRENGTH RESULTS

	Limiting Strength	**28-Day Strength**	**Standard Cured 28-Day Strength**	**Reduced 28-day Strength**	**Correlation Reduction**
Trial	**S_u (MPa)**	**S_{28} (MPa)**	**S_{S28} (MPa)**	**S_{S28R} (MPa)**	
Mix A				$S_{S28R} = 0.982*S_{S28} - 4.506$	
1	64.52	63.0	70.98		
2	64.54	62.8	68.45		
3	68.45	65.2	68.61		
4	63.79	62.2	65.49		
Average			**68.38**	**62.65**	8.4%
Mix B					
1	65.72	64.5	66.66		
2	64.99	59.7	66.41		
3	67.74	59.4	58.34*		
Average			**66.53**	**60.83**	8.6%
Mix C					
1	58.67	54.1	55.72		
2	49.96	47.2	55.21		
3	56.28	51.9	58.46		
Average			**56.46**	**50.94**	9.8%
Mix D					
1	61.10	56.6	60.62		
2	62.93	56.2	54.68**		
3	53.03	48.9	55.45		
Average			**58.03**	**52.48**	9.6%

1 MPa = 145 psi

* Not included in average - Likely affected by high tank temperature at 3 days age (see Appendix D).

** Not included in average - No explanation at this time.

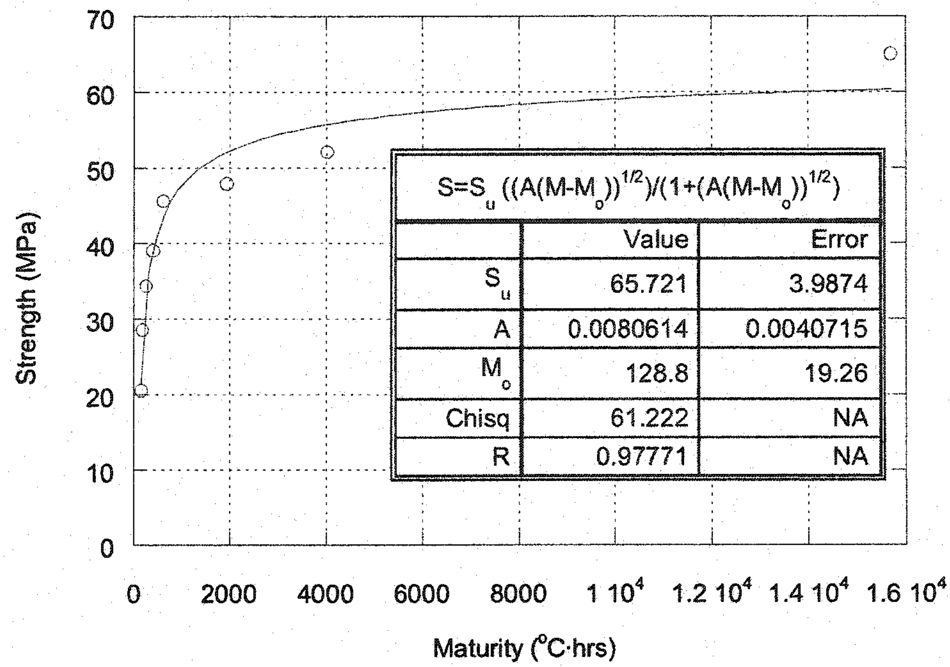


FIGURE 18: STRENGTH VERSUS MATURITY FOR MIX B - TRIAL #1

The limiting strengths were used to calculate the relative strengths at each age for each trial for each mix. Relative strengths were obtained by dividing the strength at each age by the associated limiting strength (S/S_u). Relative Strength versus Maturity was plotted for each mix that combined all trials into one plot and Equation (17) was fit to the data, Mix B is shown in Figure (19) and the remaining in Appendix (C). Equation (17) parabolic-hyperbolic was used as opposed to Equation (16) linear hyperbolic because it gave a better fit at both the early and 28-day ages.

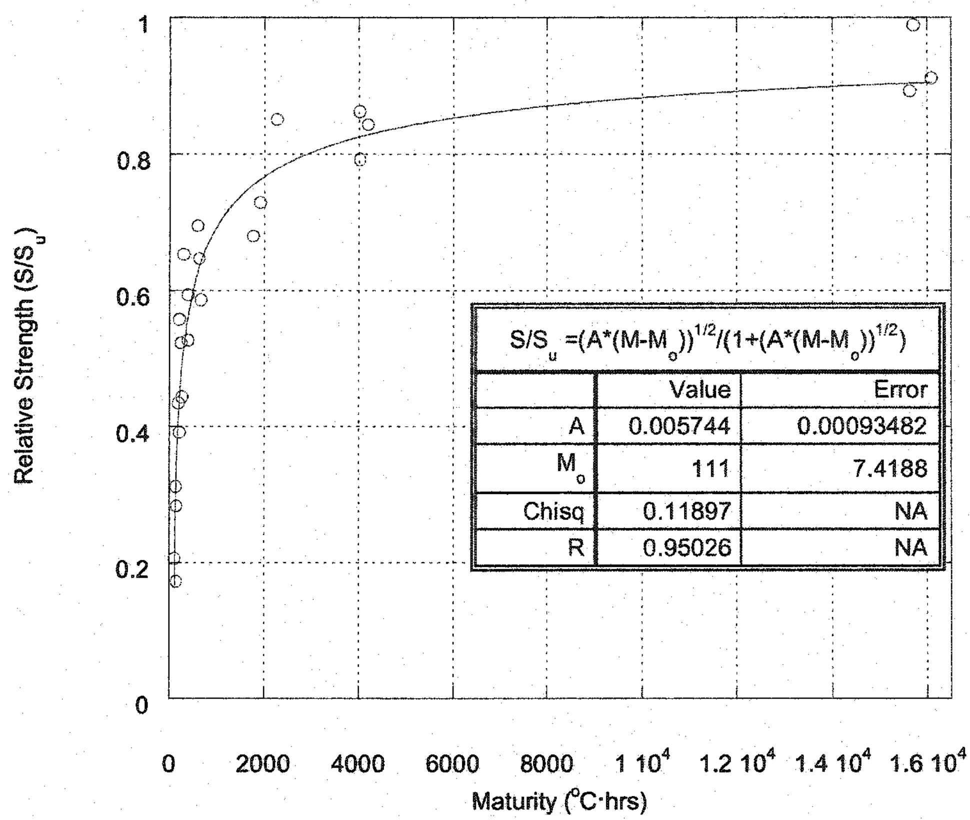


FIGURE 19: RELATIVE STRENGTH VERSUS MATURITY FOR MIX B – ALL TRIALS

4.6 REQUIRED MATURITY

Now that the relative strength-maturity relationships were created, required maturity to reach the desired release strengths were calculated and this section will describe that procedure. Two release strengths are commonly required, 24.1 or 27.6 MPa (3500 or 4000 psi) depending on the hollowcore design requirements. To satisfy the requirements of the Precast/Prestressed Concrete Institute's Manual for Quality Control MNL-116, Division 6, Section 6.2.3-2 and build further conservativeness into the system, a statistical approach was used to calculate the required maturity values.

Figures (20) to (23) contain plots of Relative Strength versus Maturity for all four mix designs at values less than 850 °C·hrs since, that is the area of the curve that will be used in this application. Also, shown in Figures (20) to (23) are the best-fit regression models of Equation (17) and the associated regression outputs. The regression values of A, M_o and *Chisq* (Chi Squared) are tabulated in Table (3). *Chisq* (Chi Squared) is defined by KaleidaGraph as the sum of the squared residuals, $\sum(y_i-\hat{y})^2$ where, $\hat{y}$ is the predicted value on the regression curve. The Residual Standard Deviations (RSD) were calculated by taking the square-root of *Chisq* divided by $n-2$ degrees of freedom, i.e. $[\sum(y_i-\hat{y})^2/(n-2)]^{1/2}$. A lower 99% confidence limit was created by assuming a normal probability distribution and subtracting $[t_{\alpha/2}*RSD/(n-2)^{1/2}]$ from the modeled curve fit, where $t_{\alpha/2}$ is a tabulated critical value of the t-distribution at the 99% confidence level (Walpole and Meyers 1993). The confidence limit curves and the regression outputs are shown in Figures (20) to (23) for each mix design. Tabulated values of the statistical regression fit are given in Table (4).

Conservatively the values of $\propto$ were taken as the ratio of required release strength to the reduced standard cured 28-day strength $(S_{release} / S_{S28R})$ as opposed to $(S_{release} / S_u)$ since S_{S28R} is the maximum strength any particular mix design can realize in an actual production cycle. The resulting values of $\propto$ can be found in Table (3). Therefore, by using Equation (19) and the necessary values of Tables (3) and (4), the values of required maturity for each mix design and both release strengths were calculated and given in Table (5).

TABLE 3: RESULTS OF REGRESSION ANALYSES (A, M_o), AND α VALUES

Mix	S_{S28R} (MPa)	A	M_o (°C·hrs)	α (24.1 MPa)	α (27.6 MPa)
A	62.65	0.006580	106.6	0.385	0.440
B	60.83	0.005744	111.0	0.397	0.454
C	50.94	0.005606	183.4	0.474	0.542
D	52.48	0.003061	162.1	0.460	0.526

1 MPa = 145 psi

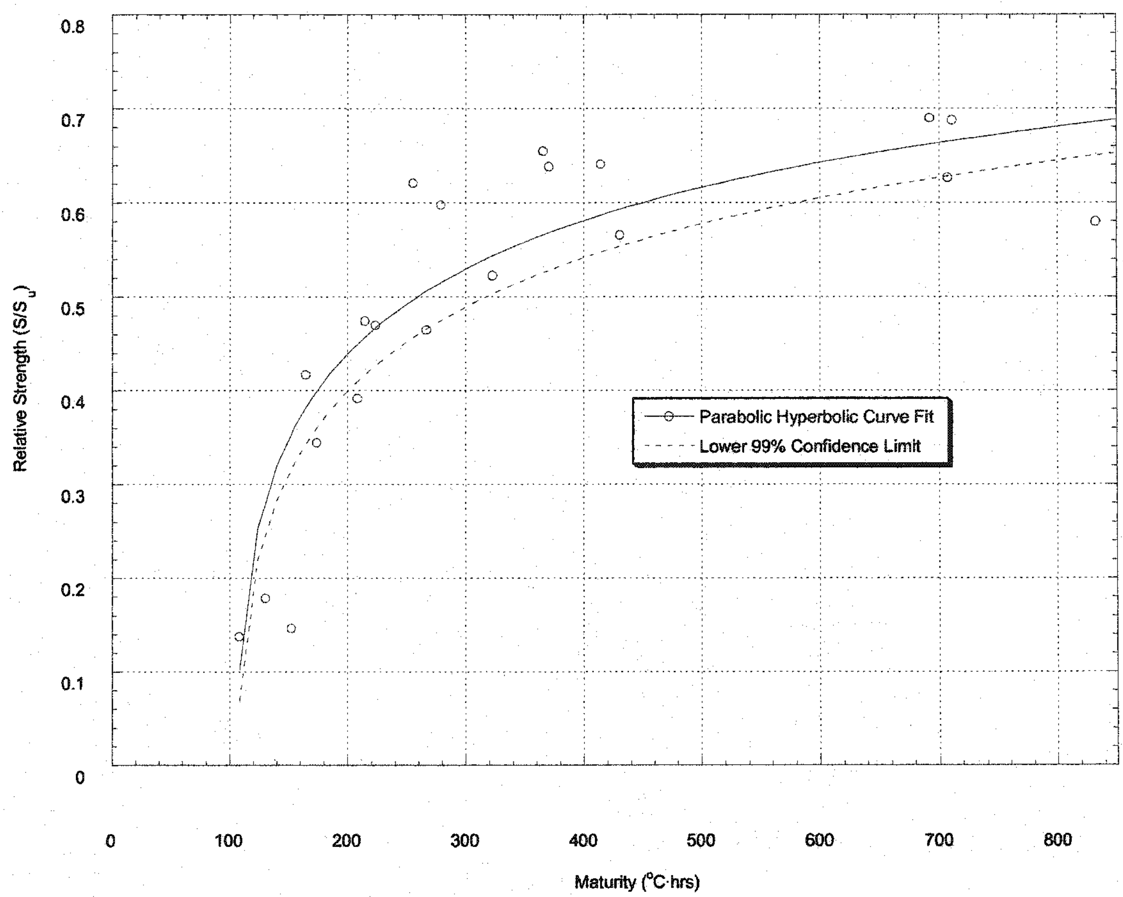
TABLE 4: REGRESSION ANALYSIS RESULTS FROM THE STATISTICAL ANALYSIS

Best Fit Resgression Values			99% Confidence Limit Values*			
Chisq	n	RSD	$t_{\alpha/2}$	$t_{\alpha/2}$*RSD/ $(n-2)^{1/2}$	A	M_o
0.1423	32	0.0689	2.741	0.03446	0.00478	107.35
0.1190	24	0.0735	2.797	0.04385	0.00383	112.23
0.0495	22	0.0498	2.819	0.03136	0.00417	184.16
0.0460	23	0.0468	2.807	0.02866	0.00235	164.05

*AS DEFINED BY (WALPOLE AND MYERS 1993)

TABLE 5: REQUIRED MATURITY VALUES

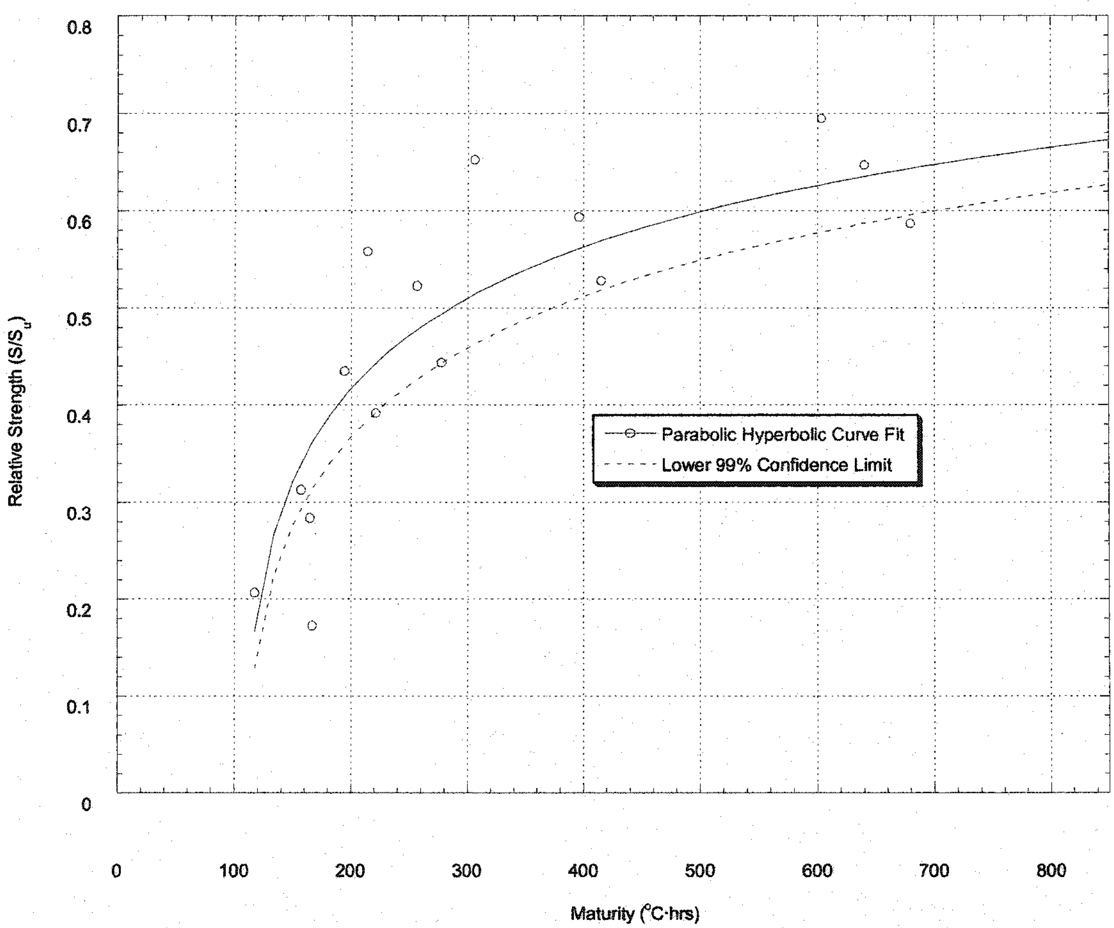
Maturity Required (°C·hrs)		
Mix	24.1 MPa	27.6 MPa
A	190	237
B	225	292
C	379	519
D	472	686



$S/S_u = (A*(M-M_o))^{1/2}/(1+(A*(M-M_o))^{1/2})$		
Regression Output	Value	Error
A	0.0065775	0.00081543
M_o	106.54	2.9111
Chisq	0.14227	NA
R	0.95632	NA

$S/S_u = (A*(M-M_o))^{1/2}/(1+(A*(M-M_o))^{1/2})$		
Lower 99% Limit	Value	Error
A	0.0047771	7.9178e-05
M_o	107.35	0.33396
Chisq	0.0026942	NA
R	0.99897	NA

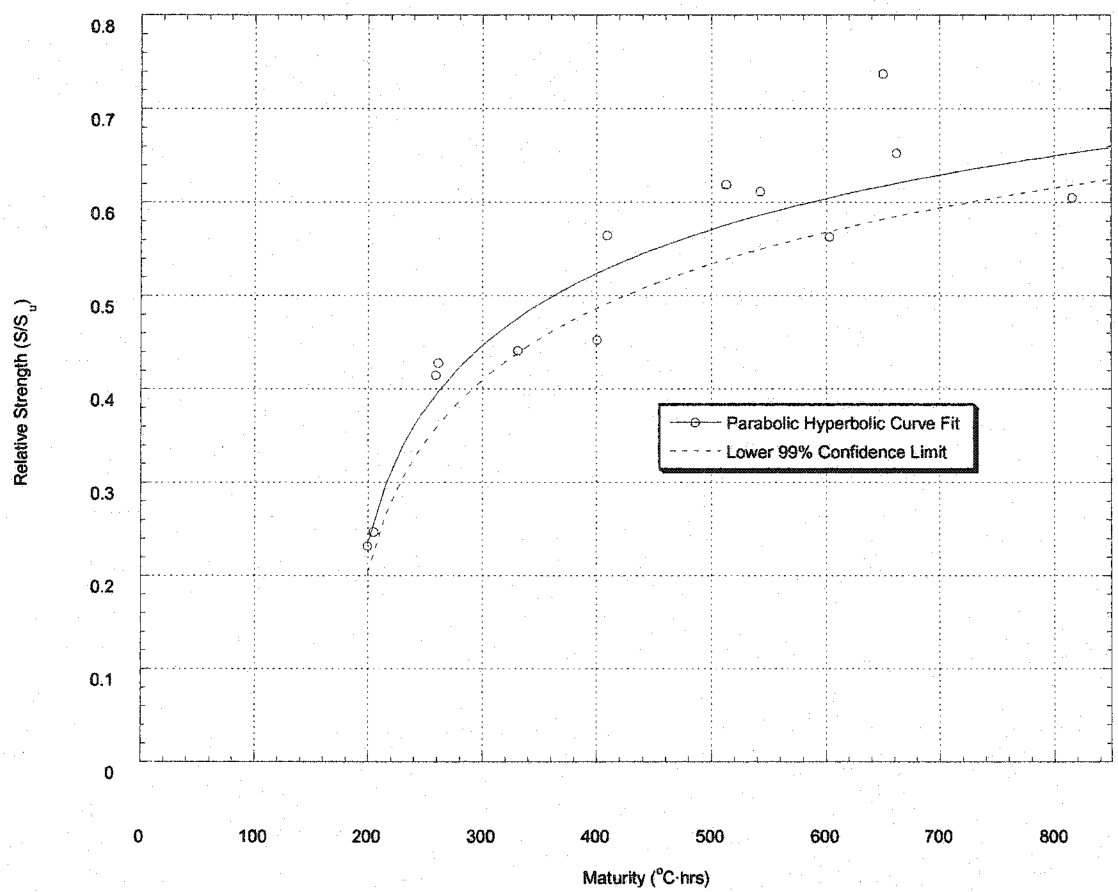
FIGURE 20: RELATIVE STRENGTH VERSUS MATURITY FOR MIX A – ALL TRIALS



$S/S_u = (A*(M-M_o))^{1/2}/(1+(A*(M-M_o))^{1/2})$		
Regression Output	Value	Error
A	0.005744	0.00093482
M_o	111	7.4188
Chisq	0.11897	NA
R	0.95026	NA

$S/S_u = (A*(M-M_o))^{1/2}/(1+(A*(M-M_o))^{1/2})$		
Lower 99% Limit	Value	Error
A	0.0038342	9.5399e-05
M_o	112.23	1.1698
Chisq	0.0029544	NA
R	0.99854	NA

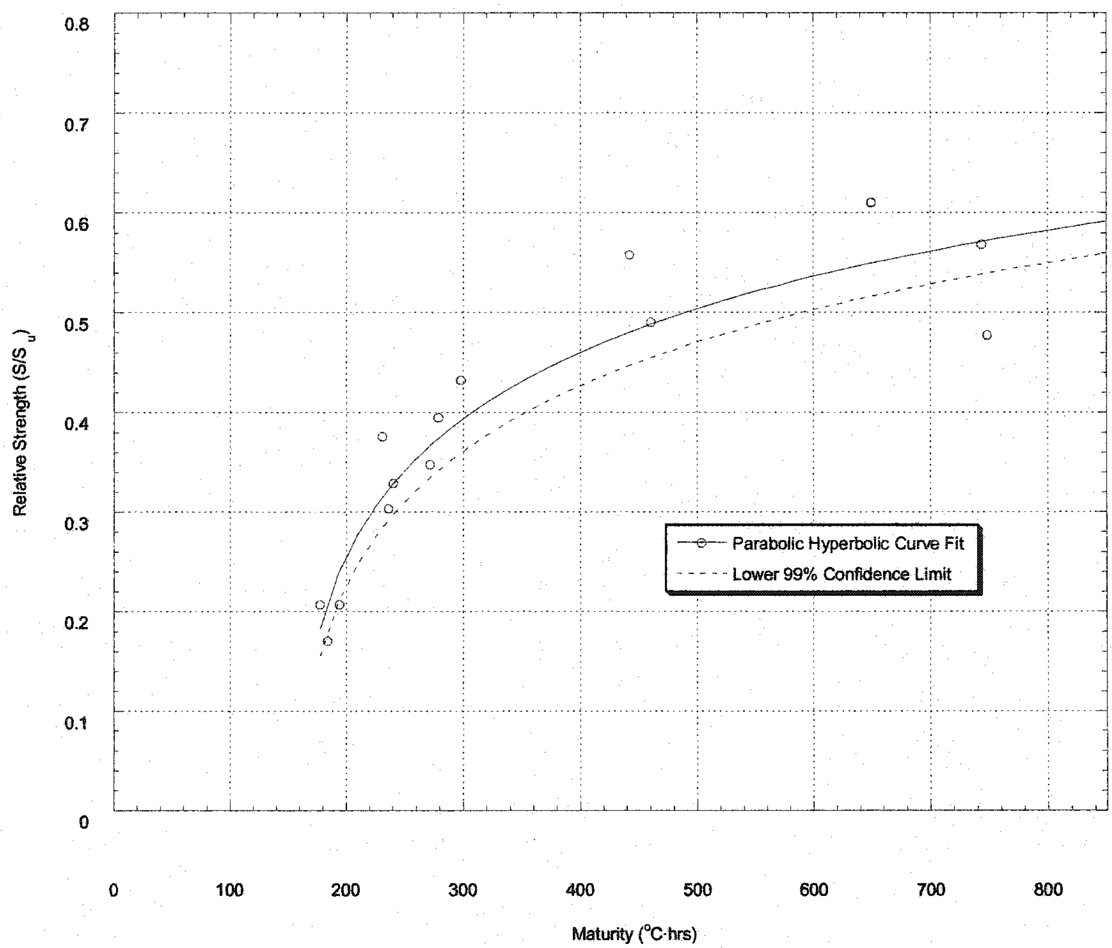
FIGURE 21: RELATIVE STRENGTH VERSUS MATURITY FOR MIX B – ALL TRIALS



$S/S_u = (A*(M-M_o))^{1/2}/(1+(A*(M-M_o))^{1/2})$		
Regression Output	Value	Error
A	0.0056057	0.0006797
M_o	183.4	7.6954
Chisq	0.049503	NA
R	0.97142	NA

$S/S_u = (A*(M-M_o))^{1/2}/(1+(A*(M-M_o))^{1/2})$		
Lower 99% Limit	Value	Error
A	0.0041734	8.4816e-05
M_o	184.16	1.3741
Chisq	0.0014862	NA
R	0.99912	NA

FIGURE 22: RELATIVE STRENGTH VERSUS MATURITY FOR MIX C – ALL TRIALS



$S/S_u=(A*(M-M_o))^{1/2}/(1+(A*(M-M_o))^{1/2})$		
Regression Output	Value	Error
A	0.0030613	0.00035154
M_o	162.13	7.7812
Chisq	0.045977	NA
R	0.98005	NA

$S/S_u=(A*(M-M_o))^{1/2}/(1+(A*(M-M_o))^{1/2})$		
Lower 99% Limit	Value	Error
A	0.0023541	3.4439e-05
M_o	164.05	1.0033
Chisq	0.00078352	NA
R	0.99966	NA

FIGURE 23: RELATIVE STRENGTH VERSUS MATURITY FOR MIX D – ALL TRIALS

4.7 CURING CYCLE HUMIDITY

It was noted in Section (3.7) that the results of the Maturity Method are dependent on the presence of adequate moisture for the progress of hydration. Therefore, measurements of the relative humidity (RH) inside the hollowcore enclosure were taken to evaluate the curing cycle.

A HOBO Pro Series data logger was placed inside one of the cores (voids) of a typical bed of hollowcore and the instrument measured relative humidity and ambient temperature. The unit did not have an external probe embedded into the concrete as was done in the strength maturity testing, it simply measured the relative humidity and temperature of the air inside the core. Figures (24, 25, and 26) illustrate measurements taken for Mixes B and D.

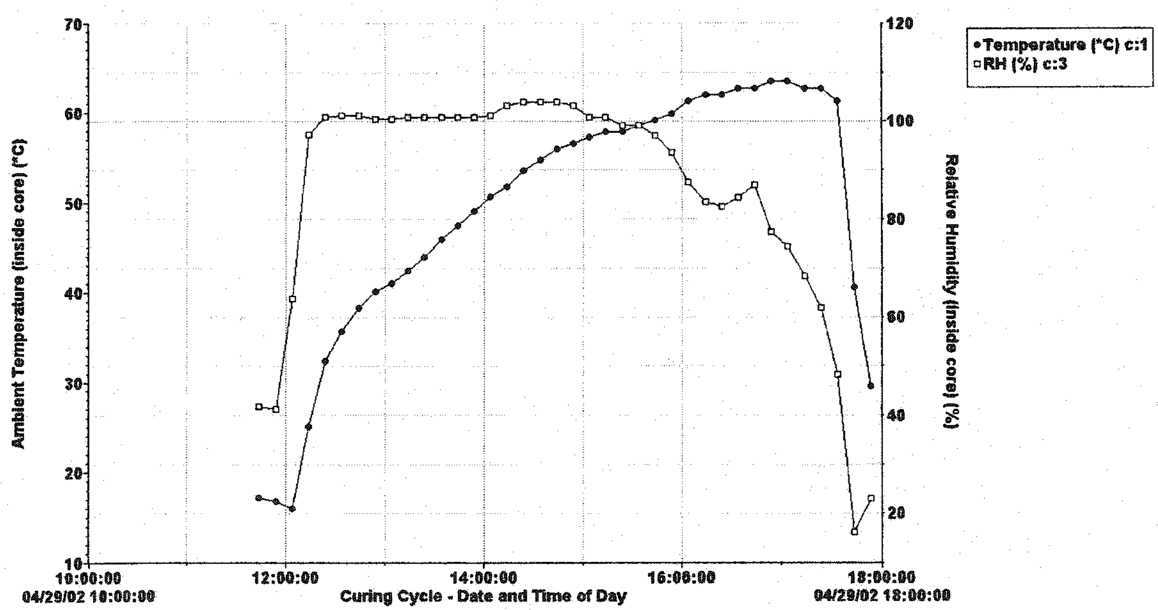


FIGURE 24: TEMPERATURE AND RELATIVE HUMIDITY – MIX B ON APRIL 29, 2002

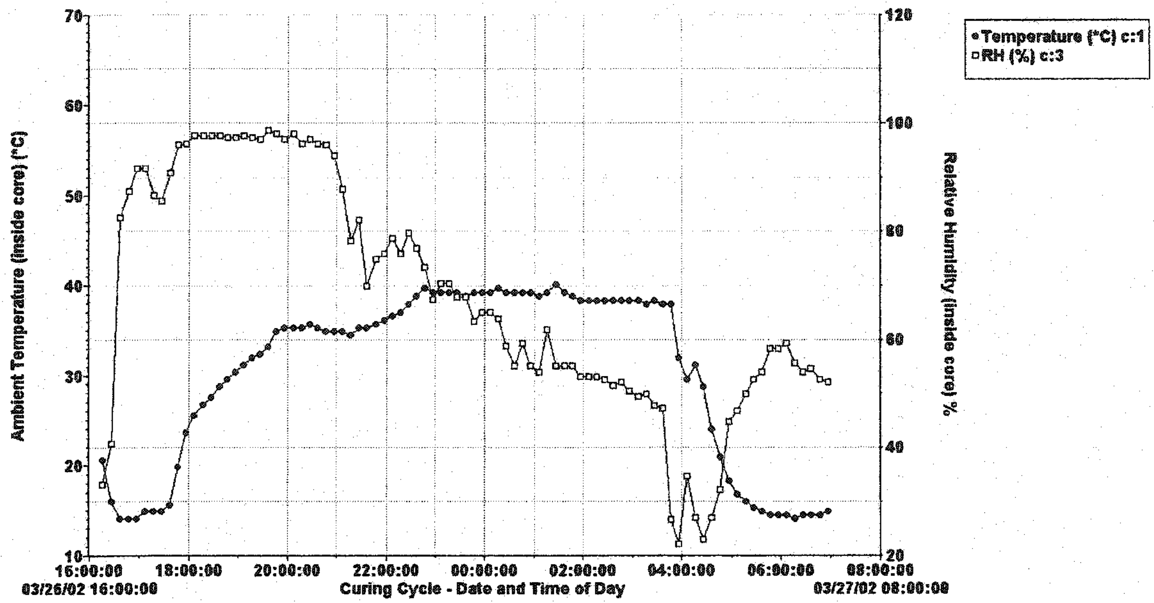


FIGURE 25: TEMPERATURE AND RELATIVE HUMIDITY – MIX D (TRIAL #2) MARCH 26, 2002 BED 2

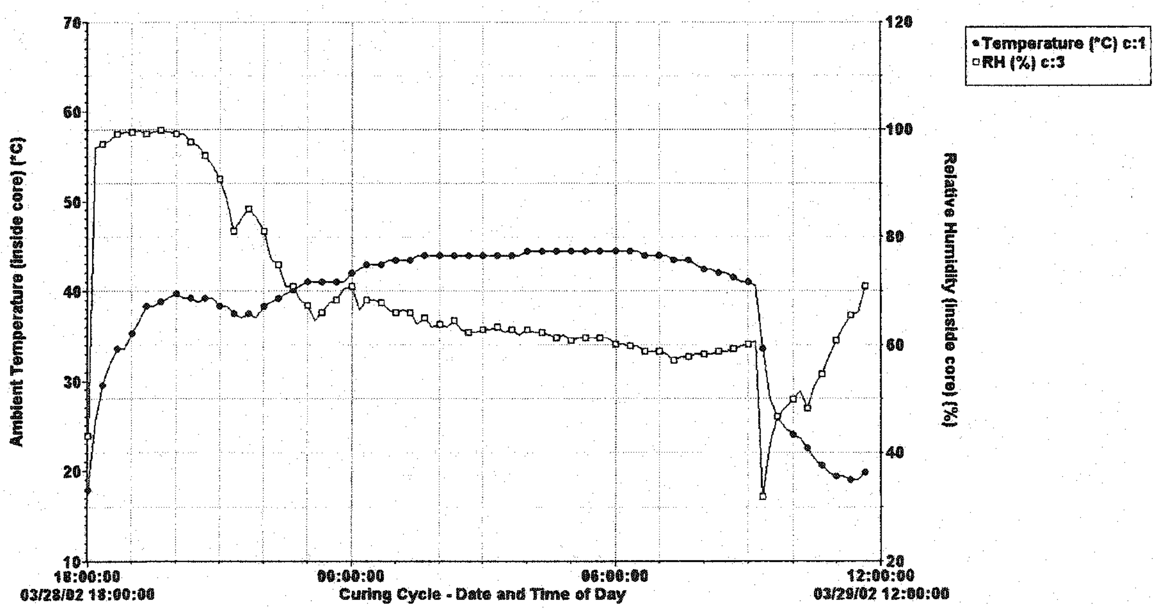


FIGURE 26: TEMPERATURE AND RELATIVE HUMIDITY – MIX D (TRIAL #3) MARCH 26, 2002 BED 4

In all three tests the RH was above 80% for the first four hours of curing. Once the concrete temperature approached its maximum the RH dropped rather rapidly until the bed was uncovered at which point the RH being measured was that of the open plant.

It has been reported that the humidity within the concrete must be at least 80% to maintain hydration (Pfeifer and Marusin 1981, Neville 1996). It should be noted here that no measurements were taken of the internal concrete moisture during its curing cycle, only ambient RH was measured.

It is known that in the case of zero slump concrete used for hollowocore, there is relatively a small amount of water in the mix. The mix has an approximate water to cementitious ratio of about 0.28 by mass. Therefore, due to the fact that there is very little water in the mix, it is postulated that by the end of the first four hours of curing the concrete has used up most of its internal moisture for hydration and strength gain, thus the tarps cannot sustain 100 % humidity of the air inside the cores.

However, all of the correlation testing (strength-maturity relationships) that was conducted used concrete samples from normal production under actual curing cycles. Therefore, as can be seen from the data in Appendix (D) the concrete strength did continue to rise during the entire accelerated curing cycle for all thirteen trials. This confirms that there was indeed enough moisture within the concrete to sustain hydration during that period and allow for strength gain. This evidence would then satisfy the moisture requirements of the modified maturity rule.

5 EQUIPMENT SELECTION AND IMPLEMENTATION

5.1 INTRODUCTION

The overall objective of this study was to eventually implement the Maturity Method into the production of hollowcore at PSI. This section outlines the requirements and selection of a maturity system that would measure concrete temperature, calculate maturity index and compare it to the required values determined in the previous chapter. Furthermore, the set-up and calibration of the equipment is also included.

5.2 MATURITY SYSTEM REQUIREMENTS

5.2.1 PRODUCTION

Providing reliable and timely information to the Production Department is a key role of Quality Control in any precast concrete operation. To maintain efficient production it is imperative that the hollowcore release strength be determined as soon as possible and that the production personnel have immediate access to that information. If there is any delay in either step the entire shift is pushed back which means extra production cost.

Furthermore, the strength estimation must be reliable. If strands are released on a bed of hollowcore with inadequate release strength, there is most likely to be strand slippage and possibly cracking (PCI MNL 116-99). That means, slabs must be examined by the Engineering Department and a decision made on their acceptability. If the defect is severe the slab will have to be reproduced, a costly outcome of improper strength determination. When slippage is frequent, additional strands may be added to a bed in anticipation of some of them slipping, another costly solution.

Therefore, the first three requirements of the maturity system are fast, accessible and reliable information. The reliability will allow the production department to select the mix design that matches the available curing time thus minimizing the total cement used. Reliability will also afford production the opportunity to schedule its labour forces according to well known, predictable results. The system should also have the capacity to send output signals that control the steam valves under the casting beds, either to increase or decrease the steam being sent to each bed and thus optimizing energy costs.

5.2.2 QUALITY CONTROL

Firstly, the maturity system shall meet the requirements of ASTM C1074 which, states it must be able to monitor and record concrete temperature as a function of time and must be accurate to +/- 1 °C. Secondly, the system must have a user friendly interface that allows the QC Inspector to input the following:

1) Bed number
2) Probe (East or West end of the Plant)
3) Target maturity index
4) Initial time interval (time from extrusion to time of start logging)
5) Initial temperature (temperature during initial time), and
6) Manual start logging.

The Programmable Logic Controller (PLC) must be able to use the *temperature-*

time factor equation to calculate maturity index in (°C·hrs) from the measured temperature and time. The system must be able to display the real-time calculated maturity from both ends of the bed and compare them to the target. The system must be able to communicate with a spreadsheet to manipulate and archive the records.

5.2.3 PLANT ENVIRONMENT

Any equipment that finds itself in the hollowcore plant must be rugged and virtually indestructible. The plant undergoes seasonal temperature fluctuations with high humidity and dust. Electrical cabinets must be well sealed and splash proof. The temperature sensors will experience temperatures reaching 70 °C and will likely be stepped on and handled roughly.

5.3 COMMERCIALLY AVAILABLE MATURITY EQUIPMENT

There is a wide range of maturity equipment on the market from single channel portable units to preprogrammed equipment designed for a plant type setting. A summary of the available equipment along with associated advantages and disadvantages as related to the application at hand is shown in Table (6).

TABLE 6: COMPARISON TABLE OF COMMERCIALLY AVAILABLE MATURITY EQUIPMENT

Maturity System	Supplier	Advantages	Disadvantages
Single Channel Maturity Meter	M&L Testing *www.mltest.com*	• Low cost • Meets ASTM C1074 accuracy	• No data acquisition • Not programmable – only uses *temperature-time function* • 12 units required • No simple method to communicate to production
Four Channel Maturity Meter	M&L Testing *www.mltest.com*	• Low cost • Programmable datum temperature • Meets ASTM C1074 accuracy	• No data acquisition • Only uses *temperature-time function* • 4 units required • No simple method to communicate to production
ConcTrol Box	SDS Company *www.concretendt.com*	• Low cost • Meets ASTM C1074 accuracy	• Single Channel • No data acquisition • Not programmable • 12 units required • No simple method to communicate to production
Con-Cure System	Con-Cure Corporation *www.Con-Cure.com*	• Meets ASTM C1074 accuracy • Data acquisition • Programmable	• High cost • Single Channel • Only uses *equivalent-age function* • No simple method to communicate to production
Maturity Control System	PCE – Elematic *www.elematic.com*	• Meets ASTM C1074 accuracy • Off the shelf purchase - preprogrammed • Capability to receive and send desired outputs (lights and valves) • Installed by supplier	• Very High cost • Only uses *temperature-time function* • Not in operation in any CSA or PCI Certified Plant in North-America • Unknown Technical Service

TABLE 6: COMPARISON TABLE OF COMMERCIALLY AVAILABLE MATURITY EQUIPMENT (CONT'D)

Maturity System	Supplier	Advantages	Disadvantages
Custom Maturity System (Datascan Data Acquisition)	Durham Instruments *www.disensors.com*	• Moderate Cost • Meets ASTM C1074 accuracy • Programmable to specific needs (*either maturity function*) • Capability to receive and send desired outputs (lights and valves) • Good track record in Plant type environment (already used in PSI Hollowcore plant during testing)	• Not in operation in any CSA or PCI Certified Plant in North-America • Unknown Technical Service • Must be installed and programmed by others
Custom Maturity System (Allen Bradley PLC)	Electrozad Supply *www.electrozad.com*	• Moderate Cost • Meets ASTM C1074 accuracy • Programmable to specific needs (*either maturity function*) • Capability to receive and send desired outputs (lights and valves) • Good track record in Plant type environment • Known Local Technical Service	• Not in operation in any CSA or PCI Certified Plant in North-America • Must be installed and programmed by others

5.4 COMPONENT SELECTION

After reviewing the features of the commercially available equipment it would seem logical to choose the equipment from PCE Elematic since it was already programmed for this type of application. However, PSI was not convinced that the price PCE was quoting for the equipment was justified. PSI believed a customized system using locally available components with known technical support was the best choice.

Therefore, after consulting with a number of suppliers the PLC chosen was an Allen Bradley *MicroLogix 1500 Series Controller*. The unit had the capacity to receive thermocouple inputs from at least twelve channels (two per bed * six beds) and perform the necessary mathematical calculations and generate the desired outputs. The user interface consists of a *Panel View Display* that accepts specified inputs and displays real-time results. The unit was also recommended because of a good track record in plant type applications and local technical support.

Since the length of the plant is 122 m (400 ft) a thermocouple temperature transmitter was required for each probe. The transmitter input is type T thermocouple (mV) and the output is a 4-20 mA signal sent the length of the plant back to the QC Office. Also, the transmitters require a 24V DC power supply. A schematic of the maturity hardware is given in Figure (27).

The logic program was written to accept all of the required inputs and calculate the maturity index for each probe. Once both ends of the bed reach the target maturity a green light can be switched on in the plant to indicate that the bed is ready and the strands can be cut.

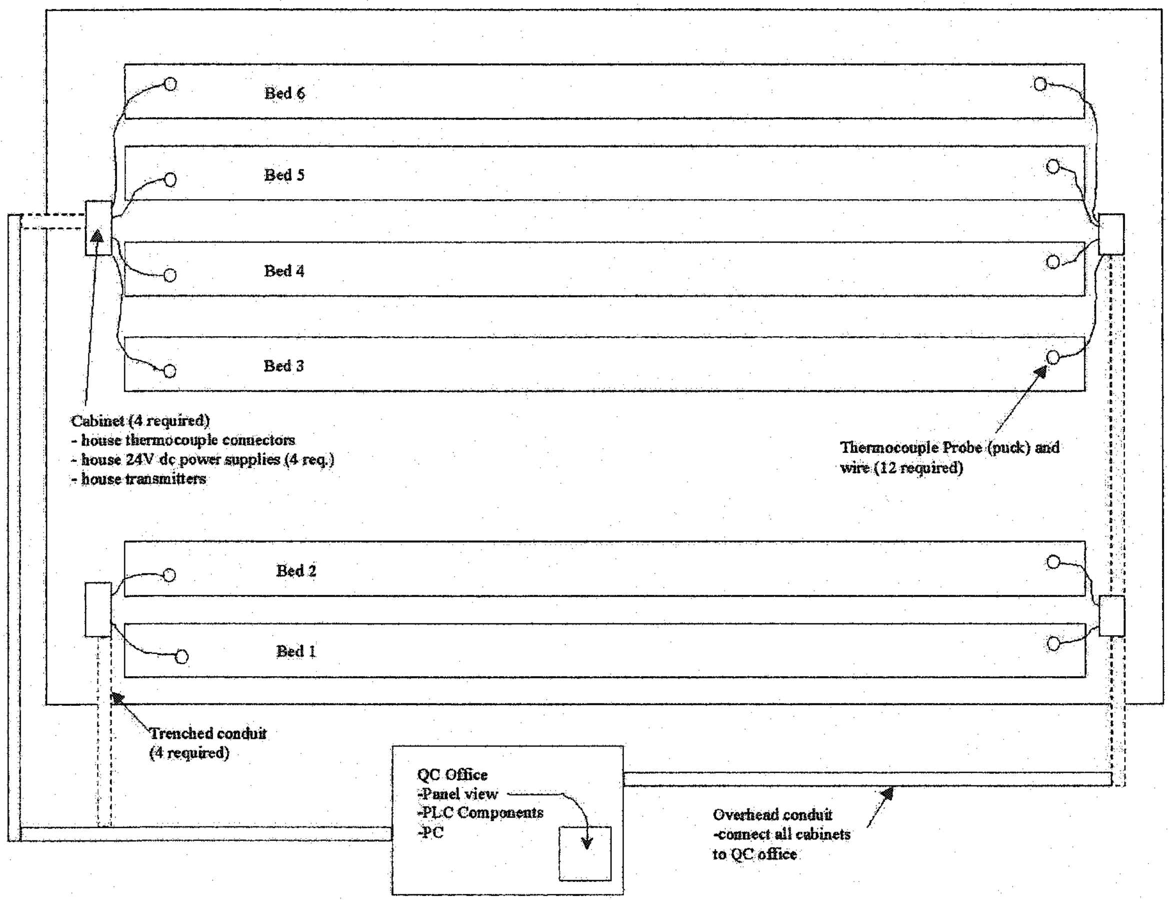


FIGURE 27: MATURITY HARDWARE SCHEMATIC - THE BED LENGTHS ARE APPROXIMATELY 122 M (400 FT)

5.4.1 THERMOCOUPLE PROBES

Before deciding on a design for the temperature sensor, measurements were taken on the hollowcore beds to determine the most reasonable location to measure temperature and calculate maturity. Eight thermocouples were used and their locations are shown in Figure (28).

The temperature profiles are shown in Figures (29) and (30). It can be seen that the highest temperature area is the bottom center and the coolest is the top outer sides of the bed. Since, the requirements for strength and slippage are most critical at the strand elevation it would be conservative to take temperature measurements on the top center portion of the bed. Furthermore, taking readings at that location allows for the use of a probe that can be placed on the bed immediately after the hollowcore is extruded.

A probe placed on top of the bed would have to withstand being walked on and being disturbed by objects such as spreaders (lifting devices) being set on it. It was decided to house the thermocouple probe inside a flat stainless steel block called a *puck*. A depiction of the *puck* design is shown in Figure (31). The probe will be secured between the *puck's* top and bottom halves once they are bolted together and the probe will protrude 6 mm (¼ inch) below the surface and be embedded into the concrete once in place. Teflon coated Type T thermocouple wire in a stainless steel armor sheathing was chosen because of its temperature range, accuracy, and ability to withstand the harsh plant environment.

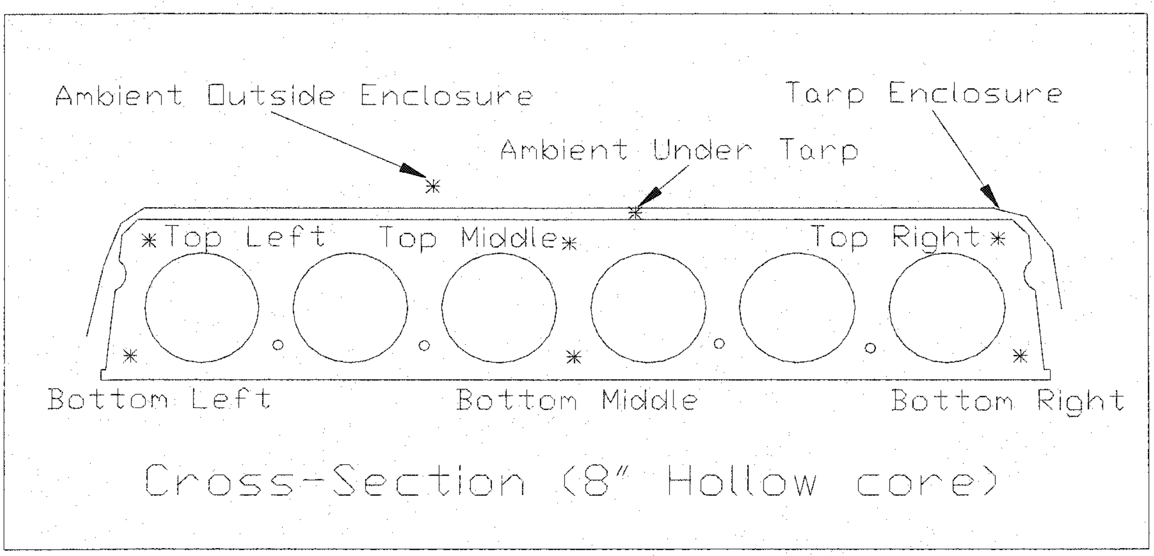


FIGURE 28: THERMOCOUPLE LOCATIONS

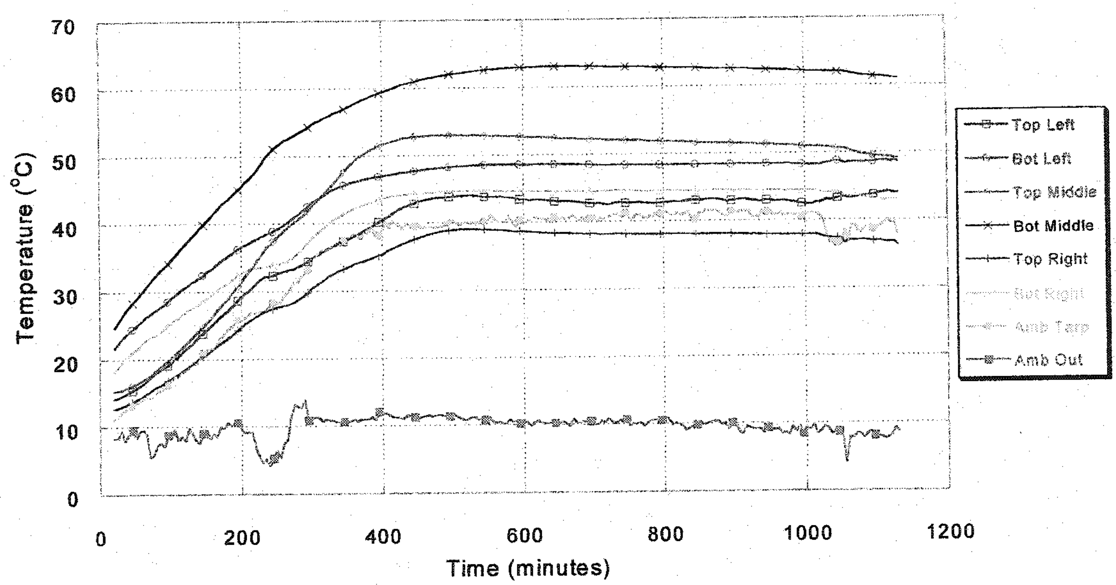


FIGURE 29: HOLLOWCORE TEMPERATURE AT VARIOUS CROSS-SECTIONAL LOCATIONS – FEB 10, 2000

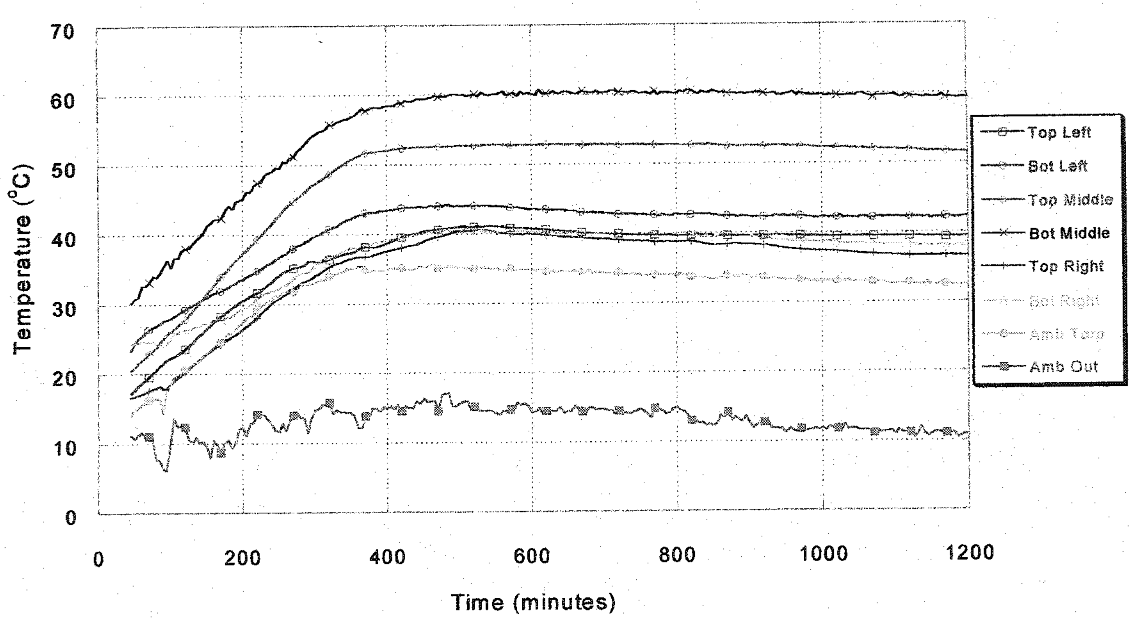


FIGURE 30: HOLLOWCORE TEMPERATURE AT VARIOUS CROSS-SECTIONAL LOCATIONS – FEB 11, 2000

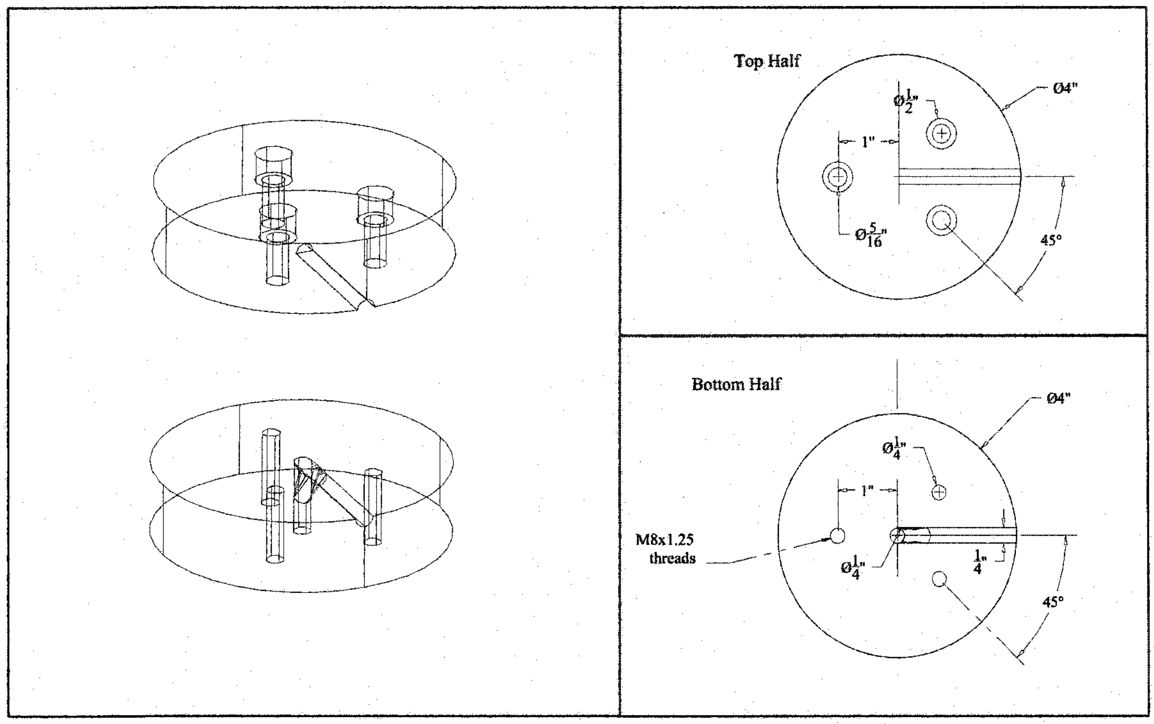


FIGURE 31: *LEFT* – ISOMETRIC VIEW OF PUCK *RIGHT* – TOP VIEW OF TOP AND BOTTOM HALF OF PUCK

It was believed that the stainless steel *puck* may have some effect on the temperature measurements because of its size and material properties. To test that hypothesis a comparison test was conducted on a bed of 203 mm (8 inch) hollowcore on April 29, 2002. A probe (assembled in a *puck*) with 9.1 m (30 ft) of extension wire was connected to a HOBO Data Logger and placed on the hollowcore bed soon after extrusion. A companion thermocouple with no covering (exposed thermocouple junction), embedded in the hollowcore at about the same depth and close to the puck, was connected to another identical HOBO Data Logger. The results are shown graphically in Figure (32).

Considering only the one test, the hypothesis that the puck/probe sensor would not indicate the same temperature as the exposed thermocouple was true. It gave readings about 2 °C lower throughout the entire test. Assuming that the exposed thermocouple provides a true reading of the hollowcore temperature, the puck/probe would be in error on the conservative side.

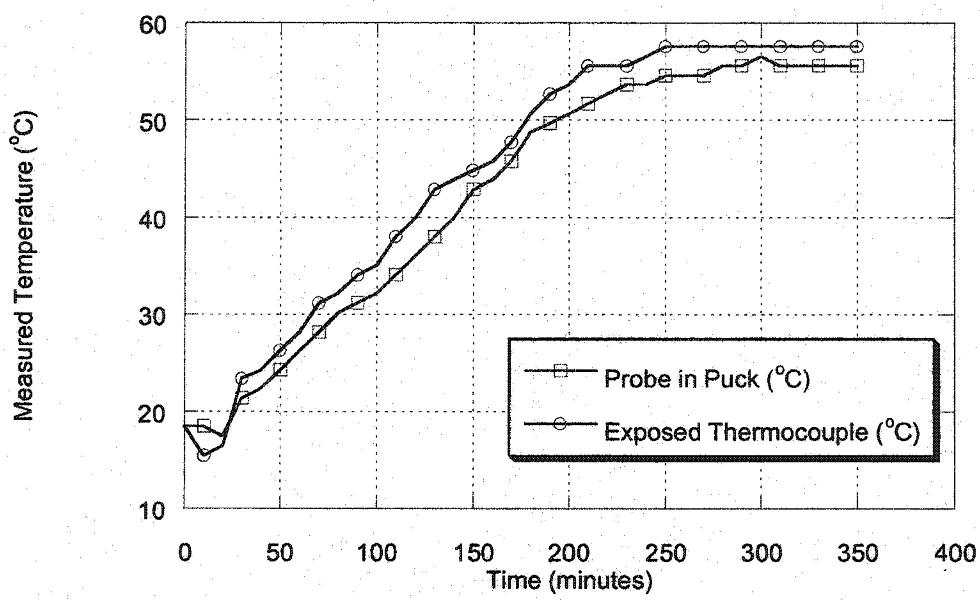


FIGURE 32: TEMPERATURE COMPARISON OF PROBE IN PUCK TO EXPOSED THERMOCOUPLE

5.5 EQUIPMENT CALIBRATION

As with any quality control tool the Maturity System must be calibrated to known physical constants or traceable to the United States National Institute of Standards and Technology (NIST). From the very beginning of the planning stage it was envisioned that the thermocouples and data acquisition system would be calibrated using de-ionized ice water and boiling water baths (0 °C and 100 °C) since that range encompasses the hollowcore curing temperatures. It was therefore the intention to have the system measure temperatures from 0 to 100 °C. However, through some miscommunication with the supplier the thermocouple transmitters were programmed to read from 10 to 70 °C only. Before the oversight was identified the PLC program was also written for that temperature range, meaning 10 °C corresponded to 4 mA and 70 °C to 20 mA. It would have been too expensive to correct the situation. Therefore, the following procedure was used to calibrate the entire system.

5.5.1 THERMOCOUPLE PROBE CALIBRATION

A process calibrator, model *Fluke 743B*, capable of reading and sourcing a thermocouple signal was rented from *Accutech Rentals Limited* located in Edmonton, Alberta. The rental unit came with a calibration certificate which can be found in Appendix (B). The low rental rate and provision of a calibration certificate made renting more attractive than purchasing such an instrument.

Since, the probe extension wires varied in length from 7.6 to 10.7 m (25 to 35 ft) each probe was calibrated as a unit. Using a sample of distilled water, *Pure Water Brand*, ice and boiling water baths were created. For the ice water bath, ice cubes were made from the selected water source, placed in an insulated container and stirred until an ice/water slurry was formed. A standard department store electric kettle was used to create the boiling water bath. One by one the probes were connected to the Fluke 743B meter to read temperature and placed in the ice water slurry which was continually stirred until the probe gave a constant reading. In the kettle the water was kept at a steady boil until the probe reading stabilized.

By examining the results, in Table (7), it can be seen that no reading fell outside of the +/- 1 °C temperature range. Consequently the probes were deemed acceptable. It should be noted that since changes in barometric pressure change the boiling point of water, the atmospheric pressure should be known for the area were the calibrations will take place. As the elevation increases the barometric pressure drops and so does the boiling point of water. Since, Windsor, Ontario is relatively close to sea level the average barometric pressure is 30 inches of Mercury (101.3 KPa) at which water boils at 100 °C.

TABLE 7: FLUKE READINGS FOR EACH PROBE IN BOTH WATER BATHS

Probe #	Deionized Ice Water Bath (°C)	Deionized Boiling Water Bath (°C)
1 East	0.1	99.6
1 West	0.1	99.5
2 East	0.0	99.4
2 West	0.1	99.4
3 East	0.1	99.5
3 West	0.1	99.3
4 East	0.2	99.4
4 West	0.0	99.5
5 East	0.1	99.0
5 West	0.4	99.6
6 East	0.1	99.5
6 West	0.0	99.5

5.5.2 DATA ACQUISITION AND TRANSMITTER CALIBRATION

Using the same Fluke 743B meter as described in section 5.5.1, the data acquisition system and transmitters were also calibrated. Using a very short piece of thermocouple wire, the Fluke was plugged into each connector at the cabinet that housed the transmitters. The meter was used to create known thermocouple signals throughout the capable range of the transmitter while a second person recorded the temperature readings from the panel view display in the QC Office. The results of the calibration are shown in Tables (8) and (9).

After each trial, transmitter potentiometer adjustments were made if necessary. The adjustments accounted for the various wire lengths and resistances. After the fourth trial all the probes were reading within the +/- 1 °C tolerance.

Since all components measured temperature within the specified tolerance it can be concluded that the entire maturity system was calibrated according to the requirements of ASTM C 1074.

TABLE 8: CALIBRATION RESULTS WITH SOURCED THERMOCOUPLE INPUTS – TRIALS 1 AND 2

Panel View Display Readings (°C) - Trial #1 July 4, 2002

Probe #	Fluke 743B Input (°C)										
	10	**15**	**20**	**30**	**40**	**45**	**50**	**55**	**60**	**65**	**70**
1 East			20	28	40				60	65	
1 West	10	15	20	29	39			53	58		
2 East			20		39		49		60	65	
2 West		16	21	30	40	50			60	66	
3 East			19		40				61	66	
3 West		15	20	29	39		50		60	65	
4 East			21		40				60	66	
4 West			20	30	40		50		60	65	
5 East			21		40		50	55	60	65	
5 West			20		40				60	65	
6 East			21		40		50		60	65	
6 West			20		40		50		60	65	

Adjustments made

Panel View Display Readings (°C) - Trial #2 July 4, 2002

Probe #	Fluke 743B Input (°C)										
	10	**15**	**20**	**30**	**40**	**45**	**50**	**55**	**60**	**65**	**70**
1 East	11			29			49				69
1 West	11		20	30	40		50		60		69
2 East											
2 West			20		40			55	61	66	
3 East	10			29			49				69
3 West			20		40				60	65	
4 East	11			30			50				71
4 West			20		40				60		
5 East	11			30			50			66	
5 West			20		40				60		
6 East	11			30			50			66	
6 West			21		40				61	66	

Adjustments made

TABLE 9: CALIBRATION RESULTS WITH SOURCED THERMOCOUPLE INPUTS – TRIALS 3 AND 4

Panel View Display Readings (°C) - Trial #3 July 5, 2002

Probe #	Fluke 743B Input (°C)										
	10	**15**	**20**	**30**	**40**	**45**	**50**	**55**	**60**	**65**	**70**
1 East			21		41				61	66	
1 West		15		30		44			60	65	
2 East			21		40				60	65	
2 West		16		31		46			61	65	
3 East		16	21		41		51		62	67	
3 West		16		31		45			61	66	
4 East		17		31		45	50		60	65	
4 West		16		31					61	65	
5 East		16		31		46			61	66	
5 West		16	20		40				60	65	
6 East		16	21		40				60	65	
6 West		16	20		40				60	65	

Adjustments made

Allen Bradley Display Readings (°C) - Trial #4 July 5, 2002

Probe #	Fluke 743B Input (°C)										
	10	**15**	**20**	**30**	**40**	**45**	**50**	**55**	**60**	**65**	**70**
1 East			21		40				61	66	
1 West											
2 East		16	20		40		50		60	65	
2 West			20		40				60	65	
3 East		16		30		45			60	65	
3 West		15		30		44			60	65	
4 East			20				49		60	65	
4 West		15	20		39				60	65	
5 East		16		30		45	50			65	
5 West											
6 East		16		30		44					
6 West			21		40				61	66	

6 DISCUSSION

6.1 INTRODUCTION

The maturity system was installed in PSI's hollowcore plant throughout the summer of 2002 and was fully operational by September 2002. During the first two weeks of September the system was used along side the zero-slump cylinder method. After the two-week trial period enough confidence in the new system was achieved to discontinue the cylinders. Therefore, after the second week of September 2002 the Maturity Method has been used exclusively to measure the concrete compressive strength at transfer and to communicate to the Production Department when the strands can be cut. Figures (33) through (36) illustrate the implementation of the maturity system in the plant.

To satisfy the objectives of the study, which were to develop a new method for more reliably measuring release strength and aid in the optimization of the manufacturing process, the following activities were conducted and described in this chapter:

1) a slippage study to evaluate the reliability of the Maturity Method, and
2) a review of the manufacturing process after the implementation of the Maturity Method, focusing on curing cycle time, mix design selection, the scheduling of labour, and energy costs.

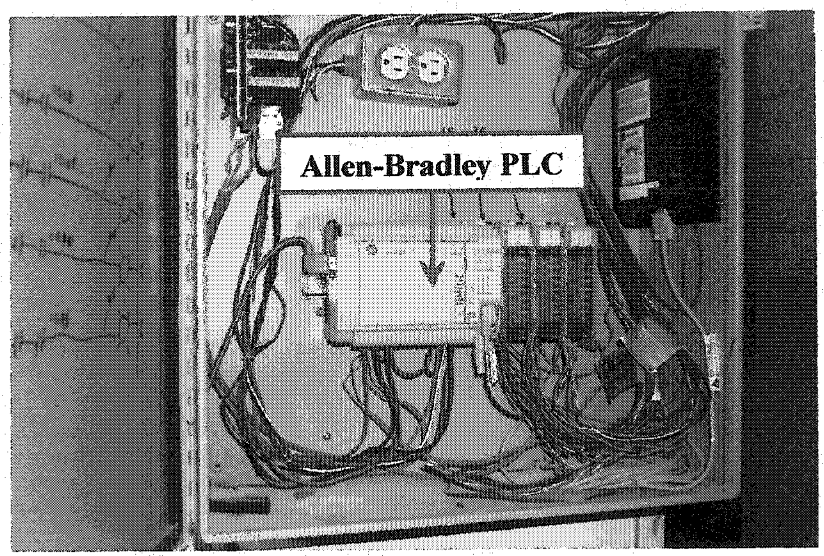


FIGURE 33: PLC COMPONENTS IN QC OFFICE

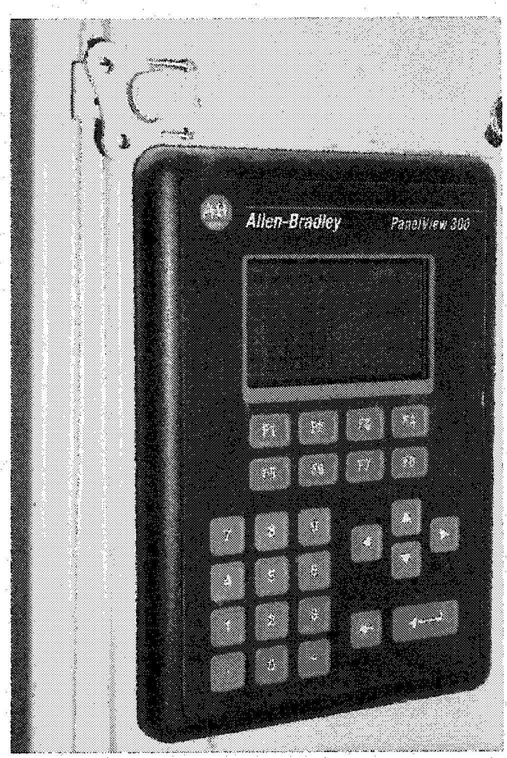


FIGURE 34: PANEL VIEW DISPLAY – MATURITY SYSTEM USER INTERFACE

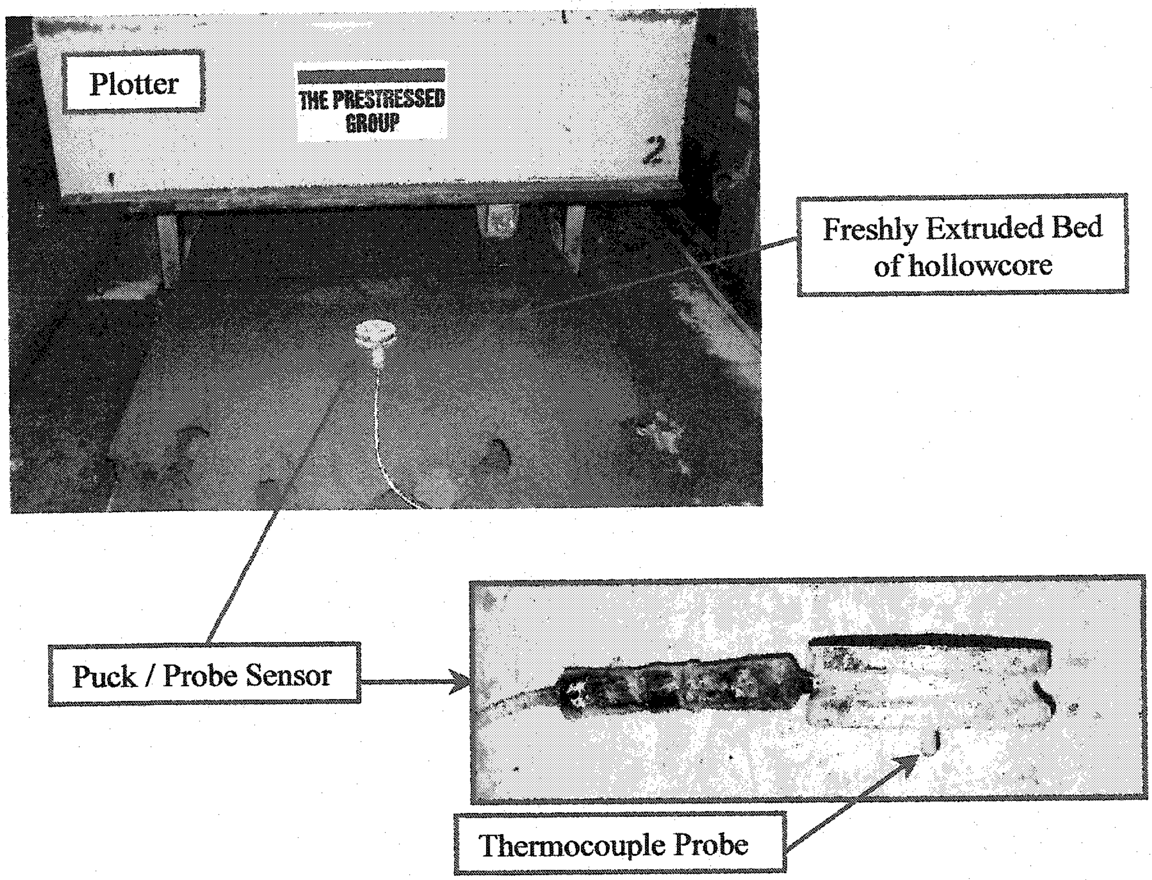


FIGURE 35: TEMPERATURE MEASURING SENSORS ON BED

FIGURE 36: BED READY LIGHT SYSTEM

6.2 SLIPPAGE STUDY

6.2.1 INTRODUCTION

This section evaluates the Maturity Method with respect to its reliability. More specifically it determines if this method can reliably measure the compressive strength of hollowcore concrete at the time of release in a production setting, by evaluating the amount of strand slippage before and after the implementation of the new method.

6.2.2 TYPES OF SLIPPAGE

In the world of hollowcore, two types of strand slippage are of concern. *Initial slippage* occurs when the prestressing strands or tendons are initially cut (released) at the very ends of the hollowcore bed with an oxy-acetylene torch. *Final slippage* may occur when the stands slip inward from the sawn face, as the 122 m (400 ft) bed of hollowcore is cut into individual slabs with a diamond tipped cross-cut saw.

Both types of slippage may affect the performance of the slabs and are therefore measured and recorded by Quality Control. Any slab that has greater than the specified tolerance of 6 mm (1/4 inch) *initial slippage* or 3 mm (1/8 inch) *final slippage* must be reviewed by the design Engineer (CSA A23.4-00 *sec. 26.2.7.2*). Often the slabs are rejected and must be reproduced. To minimize losses extra strands may be added during fabrication in anticipation of the slippage.

6.2.3 CAUSES OF SLIPPAGE

The exact cause of slippage is unknown, however there are a number of suggested theories that will be briefly introduced. First, *strand flick* is the back and forth rotational movement of the strand as the guide plates are pushed under the strands by the extruder to hold them at their proper elevation. It is thought that *strand flick* disrupts the bond between the concrete and the strand by carving a pocket around the perimeter of the strand.

Secondly, *strand vibration* is thought to be a cause of slippage. This theory suggests that if the strand touches any part of the extruder as it travels down the bed, the vibrators used to consolidate the concrete may cause the strand to vibrate and draw water to the strand-concrete interface. That excess water increases the water to cement ratio in that area and may produce a film of weak concrete around the strand.

Thirdly, the manufacturing process of the strand itself has been suspected. It was suggested that some suppliers of strand wash their strand more than once to remove die lubricants that could act as a bond breaker between the concrete and the strand.

Finally and certainly most importantly is the concrete compressive strength at the time of strand release. It is widely accepted that if the concrete strength is low the strand slippage will be high. This is the reason that the Design Engineer specifies that the concrete must have a minimum compressive strength before the strands can be cut (CSA A23.4 *sec. 26.2.7.2.1,* PCI MNL 116-99 *sec. 5.3.17*). It makes sense then that if the concrete strength at release is not accurately measured the minimum specified value may not be achieved prior to detensioning and strand slippage will occur.

6.2.4 PREVIOUS SLIPPAGE INVESTIGATION

Slippage has been an ongoing concern at PSI's hollowcore plant and was the focus of a three month investigation to determine a cause. The investigation took place in March, April and May of 2002 in an attempt to link slippage to a particular; extruder, bed, time of day, strand position, size of product, mix design, or adequate release strength (measured by the cylinder method). Table (10) summarizes the study variables and the test data is given graphically in Figure (37) with the complete set of records in Appendix (E).

By examining the data and Figure (37) it is evident that:

1) the largest proportion of slippage occurred on the 254 mm (10 inch) product,
2) mix 3 had the most slippage of the mixes,
3) the slippage was fairly evenly distributed amongst the beds and sets of beds, and
4) in March, 11% of the slabs with slippage occurred on beds that had a lower than specified cylinder strength and in April and May no low cylinder strengths were observed.

It should be noted that the slippage occurring in the 254 mm (10 inch) product was distributed among the three 254 mm (10 inch) extruders used during that time. Also, mix 3 is the most common mix design used during that time of year. Furthermore, all of the slippage that occurred in April and May was on beds that had sufficient release strength according to the results of the cylinder method.

Since, no single variable was predominant, identification of the exact cause of slippage was not possible. Simply, most of the slippage was occurring on 254 mm (10 inch) product.

TABLE 10: A LEGEND OF NECESSARY INFORMATION FOR THE SLIPPAGE INVESTIGATION

Item		Description
Extruder #	001	10" Extruder
	002	10" Extruder
	003	8" Extruder
	004	6" Extruder
	005	8" Extruder
	006	12" Extruder
	008	8" Extruder straight side
	010	8" Extruder
	Wh 8	8" Whisper Extruder
	Wh 10	10" Whisper Extruder
Set	1	First 2 beds of production (day shift)
	2	Second 2 beds of production (day shift)
	3	Third 2 beds of production (day shift)
	4	First 2 beds of production (night shift)
	5	Second 2 beds of production (night shift)
Cables	T	Top Strands
	BO	Bottom outer strands
	BI	Bottom inner strands
Size	6	6" Hollowcore
	8	8" Hollowcore
	10	10" Hollowcore
	12	12" Hollowcore
	14	14" Hollowcore
Mix	1	1400 of Type 30
lbs / 2 cuy	2	1300 of Type 30
	3	1200 of Type 30
	4	900 of Type 10 and 300 of Type 30
	5	900 of Type 10 and 300 of Type 30 and
		200 of Fly Ash
Release Strength	Fail	If the cylinders strength was below specified

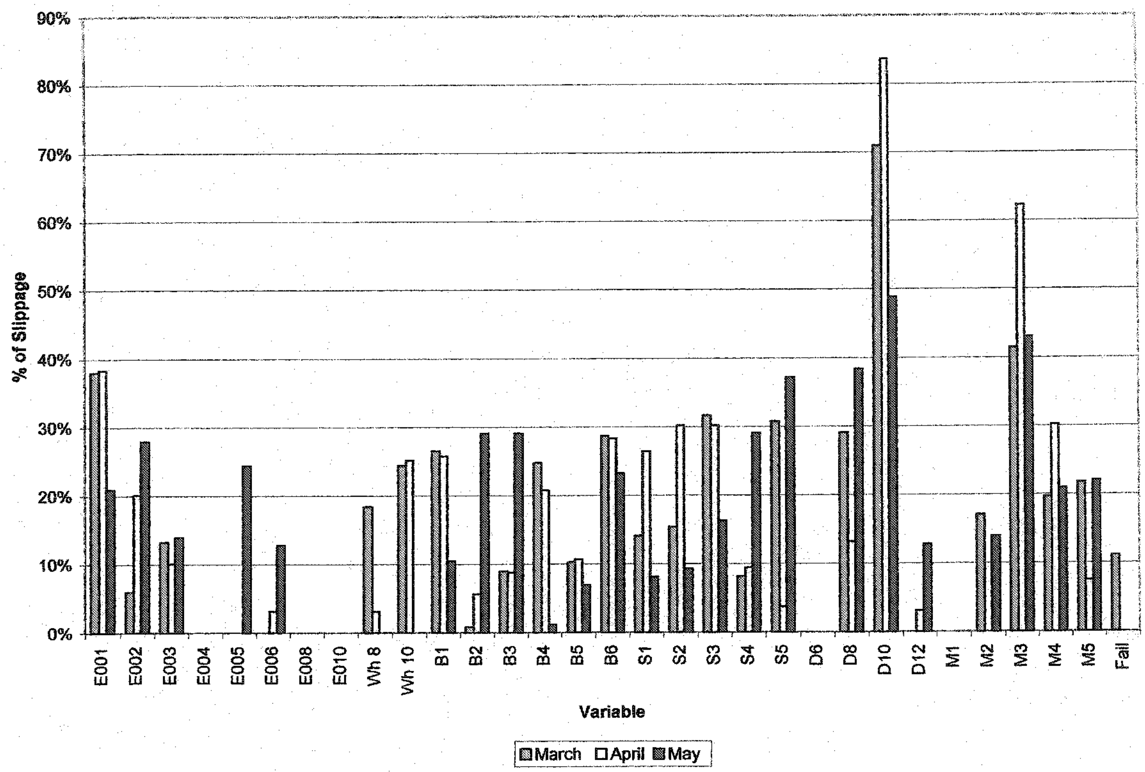


FIGURE 37: SLIPPAGE INVESTIGATION RESULTS SUMMARY – MARCH, APRIL AND MAY 2002

6.2.5 SLIPPAGE STUDY RESULTS

After reviewing the data on slippage and knowing that the plant still had ongoing slippage problems, it was decided to study whether the Maturity Method had a positive or negative effect on slippage. Doing so would give an indication of how reliable the Maturity Method was in measuring the release strength and subsequently the time to detension the hollowcore, thus providing an actual measure of the effectiveness of the Maturity Method and its benefits in a plant setting. This section will give the results of a slippage study that compared the number of hollowcore slabs being produced per month with out of tolerance slippage, before and after the implementation of the Maturity Method.

The Maturity Method completely replaced the zero-slump cylinder method by the third week of September 2002. Slippage data taken from the monthly Quality Control reports at PSI are given in Table (11). A t-test was conducted on the initial and final slippage data to evaluate the effects of the Maturity Method and the results are given in Table (12). The t-test compared the mean values of initial and final slippage for the months of February 2002 to August 2002 to the mean values of initial and final slippage for the months of September 2002 to December 2002. Since we were interested in knowing if the Maturity Method would increase or decrease the amount of slippage the results of the two-sided test were examined. Therefore, Table (12) shows that with no other steps taken to reduce slippage, there is a 96% probability for initial slippage and 98% probability for final slippage that the reduction in out of tolerance slippage was caused by the implementation of Maturity Method and not due to chance.

This data strongly suggests that the Maturity Method is giving valid measurements of the concrete compressive strength at release and is indicating the proper time to detension the strands. However, one could argue that perhaps the method is very conservative and underestimates the strength. If that were true either the curing cycle would have to be lengthened or the temperature raised to reach the required values of maturity index.

Actually, the curing cycle was not lengthened and the boiler maintained the same output with this method. The curing times (or times to reach Required Maturity) and maximum temperature reached during the accelerated curing cycle for the second week of October 2002 is given in Table (13). The time to reach Required Maturity was inline with the requirements of the production cycle and ranged from 5 to 7 hours, depending on the heating capabilities of the particular bed.

Therefore, it is concluded that the Maturity Method measures the hollowcore concrete compressive strength at release more reliably than the zero-slump cylinder method and this is supported by the slippage data. These results also confirm that the *temperature-time factor* maturity function, with a **0** °C datum temperature, can be successfully used to calculate maturity and subsequently compressive strength of zero slump high performance concrete at early ages commonly used in the precast concrete industry.

TABLE 11: NUMBER OF SLABS WITH OUT OF TOLERANCE INITIAL AND FINAL SLIPPAGE FROM PSI

Month	Number of Slabs with Initial Slippage	Number of Slabs with Final Slippage	Total No. of Pieces
Feb '02			
Total	19	143	4792
%	0.40%	2.98%	% of Total
Mar '02			
Total	29	234	4301
%	0.67%	5.44%	% of Total
Apr '02			
Total	23	159	4337
%	0.53%	3.67%	% of Total
May '02			
Total	9	86	4177
%	0.22%	2.06%	% of Total
Jun '02			
Total	9	47	2674
%	0.34%	1.76%	% of Total
Jul '02			
Total	6	64	3237
%	0.19%	1.98%	% of Total
Aug '02			
Total	3	98	3203
%	0.09%	3.06%	% of Total
Sep '02			
Total	3	19	2919
%	0.09%	1.00%	% of Total
Oct '02			
Total	2	9	4200
%	0.05%	0.21%	% of Total
Nov '02			
Total	1	5	4973
%	0.02%	0.10%	% of Total
Dec '02			
Total	1	28	3135
%	0.03%	0.89%	% of Total

Pre-Maturity

Post-Maturity

TABLE 12: RESULTS OF THE t-TEST ON THE SLIPPAGE DATA

t-Test: Two-Sample Assuming Equal Variances	Initial Slippage Feb - Aug '02	Initial Slippage Sept - Dec '02	Final Slippage Feb - Aug '02	Final Slippage Sept - Dec '02
Mean	14	1.75	118.7143	15.25
Variance	94.3333	0.9167	4189.9048	106.9167
Observations	7	4	7	4
Pooled Variance	63.1944		2828.9087	
Hypothesized Mean Difference	0		0	
df	9		9	
t Stat	2.4586		3.1036	
P(T<=t) one-tail	0.0181		0.0063	
t Critical one-tail	1.8331		1.8331	
P(T<=t) two-tail	0.0362		0.0126	
t Critical two-tail	2.2622		2.2622	

TABLE 13: MAXIMUM TEMPERATURE DURING THE CURING CYCLE AND TIME TO REACH REQUIRED MATURITY

Oct. 2002	BED No. 1		BED No. 2		BED No. 3		BED No. 4		BED No. 5		BED No. 6	
DATE	Curing Time (hr)	Max. Temp. (oC)	Curing Time (hr)	Max. Temp. (oC)	Curing Time (hr)	Max. Temp. (oC)	Curing Time (hr)	Max. Temp. (oC)	Curing Time (hr)	Max. Temp. (oC)	Curing Time (hr)	Max. Temp. (oC)
Oct 7-02 Days	5.5	54	6	49	6	44	6.5	57				
Nights	5	57	7	48					6	47	5	54
Oct 8-02 Days					5.5	53	5	52	7	41	6	43
Nights	5	52	5.5	51								
Oct 9-02 Days	5	52	5.5	51					6	51	6	45
Nights					6	46	6	54	6	45	6	54
Oct 10-02 Days	6	66	6	54	6	43	6	54				
Nights	6	51	6	47					5.75	52	5	55
Oct 11-02 Days					5.75	51	6	53	6.25	49	5.5	57
Nights	6	50	6.75	43	6.5	46	5.25	57				

6.3 MANUFACTURING HOLLOWCORE USING MATURITY

6.3.1 INTRODUCTION

This section evaluates the Maturity Method as a tool in the optimization of the manufacturing process of hollowcore. As stated in Section (2.6) the goal of this research was to determine whether cost savings with respect to mix design, labour and curing energy could be realized at PSI if the cylinder method was replaced with a more reliable method of estimating release strength. Since, all three of those areas are interrelated they will be discussed together in this section.

6.3.2 MATURITY METHOD AND MIX DESIGN SELECTION

It was concluded in Section (6.2.5) that the Maturity Method is more reliable than the zero-slump cylinder method for the application at hand. The focus of the following discussion was to determine if improved reliability equates to minimization of production cost.

Firstly, if the production department can be provided with accurate and timely information it can make well-informed decisions. By using actual average curing cycle lengths, such as those in Table (13), the Production Department can choose the appropriate mix design that matches productivity requirements or vice versa, schedule the labour according to the mix design and available casting beds.

Prior to the introduction of the Maturity Method the Production Department was relying on information that was incomplete and unreliable. It left the door open for extra cost by either choosing a mix that was too rich or too lean. If the mix was too rich, it would have a large quantity of cement and would likely achieve its specified strength before the next shift starts. If the mix was too lean the bed would not be ready until well after the next shift starts. Therefore, without using actual dollar values cost optimization of the mix design and labour can be realized.

6.3.3 MATURITY METHOD AND LABOUR SCHEDULING

Since the Maturity Method has the ability to calculate and display real-time results, the Production Department can be continuously informed. For example, assume a mechanical break down delays the day shift bed(s) from being completed on schedule. When the night shift crew arrives it will know precisely how long it will have to wait before it can cut cables and begin to strip the bed(s). If it is only ten minutes, the crew can start to get ready, if it will be one hour the workers can initiate some clean-up or other preparatory work. This feature of the Maturity Method allows for cost optimization with respect to scheduling the labour force.

6.3.4 MATURITY METHOD AND SLIPPAGE

A cost saving associated with slippage was not envisioned in the infancy of this research. Every slab that has out of tolerance slippage must be flagged by Quality Control and reviewed by the Design Engineer. The 5% of total hollowcore production with slippage, experienced in March 2002 at PSI, equated to substantial time and cost to the Design Engineer as well as the Quality Control Department. Furthermore, once the Engineering Department regains confidence in the reduced slippage numbers the extra strands used in anticipation of the slippage can be eliminated. Therefore, by reducing the number of hollowcore slabs being produced with out of tolerance slippage, the Maturity Method has reduced Production and Engineering cost.

6.3.5 MATURITY METHOD AND CURING ENERGY

There is one area of cost optimization that has not been discussed up to this point and that is the energy associated with accelerated curing. Since, the hollowcore plant at PSI does not currently have the capability of utilizing all of the outputs of the Maturity System, cost optimization has not yet been taken advantage of in this area.

When the plant undertakes the replacement of its hollowcore casting beds and steam lines in the winter of 2003, it could install electrically controlled modulating valves in the new pipeline manifold. That would enable the Maturity System to communicate with the valves to allow more or less steam to be pumped to any given bed depending on the rate of strength development compared to the available curing time. Furthermore, once a bed achieves its Required Maturity the steam could be ramped down to minimize excess heat and energy cost.

7 CONCLUSIONS

The goal of this study was to aid in the optimization of the manufacturing process used to fabricate precast hollowcore slabs by implementing the Maturity Method to measure concrete compressive strength at the prestress transfer stage. The Maturity Method is a non-destructive test that estimates concrete compressive strength by measuring temperature history.

Following the guidelines of ASTM C 1074, an experimental study was used to select the most appropriate maturity function, *temperature-time factor* or *equivalent age*, to calculate values of maturity index for the zero slump concrete. The study determined that the *temperature-time factor* maturity function with a datum temperature of **0 °C** was appropriate to model the strength gain of hollowcore concrete cured between 20 and 65 °C.

Four hollowcore mixes were used for a correlation study to create relative strength versus maturity relationships. By using a statistical approach the required values of maturity index for each mix design, that represents 24.1 and 27.6 MPa (3500 and 4000 psi) compressive release strength, were calculated and are shown below;

Maturity Required (°C·hrs)		
Mix	**24.1 MPa**	**27.6 MPa**
A	190	237
B	225	292
C	379	519
D	472	686

The selection criteria of an appropriate maturity system was outlined and various maturity systems were summarized with advantages and disadvantages. The system chosen was a locally supplied Allen Bradley PLC because of its good track record and local technical support. The calibration results verified the installed system is in compliance with ASTM C 1074. Further testing confirmed the temperature probe design is adequate to measure temperature of the curing hollowcore.

A slippage study using Quality Control records from PSI indicated that the Maturity Method more reliably estimates concrete compressive strength at the time of tendon release than the zero slump cylinder method. The data showed that the number of slabs produced per month, with out of tolerance slippage, has been significantly reduced by implementing the Maturity Method. According to the results of a t-test, there is a 96% probability for initial slippage and 98% probability for final slippage, that the reduction in out of tolerance slippage was caused by the implementation of Maturity Method and not due to chance.

Furthermore, the Maturity Method has aided the Production Department at PSI in optimizing the production costs with respect to mix design and labour by providing accurate real-time information. It was also discussed how the Maturity Method may be utilized in a hollowcore plant to optimize the energy costs associated with accelerated curing by communicating with valves in the heating system.

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APPENDIX A – MIX DESIGN DETAILS

1) Mix A

2) Mix B

3) Mix C

4) Mix D

Mix A CONCRETE MIX DESIGN

Company:	The Prestressed Group	Strength	7000 psi
Mix Designation:	HC-1	Mod. No.:	Metric
*Air:	2.0 ± 1.5 %	Slump:	zero
* Entrapped air is generally around 1.5%			
Total Cmt:	386 kg/m^3	w/c =	0.28

Note:

Zero Slump Concrete

Stone S.G. = 2.81 (175 PCF), absorption = 0.4 % , 16 mm Nominal Maximum Size

Sand S.G. = 2.55 (159 PCF), absorption = 1.5 to 2.0 %, Fineness Modulus = 2.6 +/- 0.2

DESIGN (kg/m^3) Abs. Vol.					
		Mass (kg/m3)	Material	Source	Description
Cementing Materials:			Type 10	St. Lawrence Cement	
	100%	386	Type 30	St. Lawrence Cement	
			Fly Ash (C)	Lafarge - Great Lakes Fly Ash	
Aggregate:	45%	1068	Stone	Lafarge Manitoulin	
	55%	1290	Sand	Erie Sand and Gravel	
Water:		110			
Admixtures:		260	ml/100kg of Cement - Rheomix 730fcs by Master Builders 65 ml/100 kg = 1 oz/100 lb 1 kg/m^3 = 1.6855 lb/yd^3		

Mix B CONCRETE MIX DESIGN

Company:	The Prestressed Group	Strength	6000 psi
Mix Designation:	HC-1	Mod. No.:	Metric
*Air:	2.0 ± 1.5 %	Slump:	zero
* Entrapped air is generally around 1.5%			
Total Cmt:	356 kg/m³	w/c =	0.28

Note:

Zero Slump Concrete

Stone S.G. = 2.81 (175 PCF), absorption = 0.4 % , 16 mm Nominal Maximum Size

Sand S.G. = 2.55 (159 PCF), absorption = 1.5 to 2.0 %, Fineness Modulus = 2.6 +/- 0.2

DESIGN (kg/m³) Abs. Vol.		Mass (kg/m3)	Material	Source Description
Cementing Materials:			Type 10	St. Lawrence Cement
	100%	356	Type 30	St. Lawrence Cement
			Fly Ash (C)	Lafarge - Great Lakes Fly Ash
Aggregate:	45%	1068	Stone	Lafarge Manitoulin
	55%	1290	Sand	Erie Sand and Gravel
Water:		100		
Admixtures:		240	ml/100kg of Cement - Rheomix 730fcs by Master Builders 65 ml/100 kg = 1 oz/100 lb 1 kg/m³ = 1.6855 lb/yd³	

Mix C CONCRETE MIX DESIGN

Company:	The Prestressed Group	Strength	6000 psi
Mix Designation:	HC-1	Mod. No.:	Metric
*Air:	2.0 ± 1.5 %	Slump:	zero
* Entrapped air is generally around 1.5%			
Total Cmt:	356 kg/m³	w/c =	0.28

Note:

Zero Slump Concrete

Stone S.G. = 2.81 (175 PCF), absorption = 0.4 % , 16 mm Nominal Maximum Size

Sand S.G. = 2.55 (159 PCF), absorption = 1.5 to 2.0 %, Fineness Modulus = 2.6 +/- 0.2

DESIGN (kg/m³) Abs. Vol.				
		Mass (kg/m3)	Material	Source Description
Cementing Materials:	75%	267	Type 10	St. Lawrence Cement
	25%	89	Type 30	St. Lawrence Cement
			Fly Ash (C)	Lafarge - Great Lakes Fly Ash
Aggregate:	45%	1068	Stone	Lafarge Manitoulin
	55%	1290	Sand	Erie Sand and Gravel
Water:		100		
Admixtures:		240	ml/100kg of Cement - Rheomix 730fcs Water Reducer by Master Builders 65 ml/100 kg = 1 oz/100 lb 1 kg/m³ = 1.6855 lb/yd³	

Mix D CONCRETE MIX DESIGN

Company:	The Prestressed Group	Strength	6000 psi
Mix Designation:	HC-1	Mod. No.:	Metric
*Air:	2.0 ± 1.5 %	Slump:	zero
* Entrapped air is generally around 1.5%			
Total Cmt:	356 kg/m³	w/c =	0.28

Note:

Zero Slump Concrete

Stone S.G. = 2.81 (175 PCF), absorption = 0.4 % , 16 mm Nominal Maximum Size

Sand S.G. = 2.55 (159 PCF), absorption = 1.5 to 2.0 %, Fineness Modulus = 2.6 +/- 0.2

DESIGN (kg/m³) Abs. Vol.				
		Mass (kg/m3)	Material	Source / Description
Cementing Materials:	58%	207	Type 10	St. Lawrence Cement
	25%	89	Type 30	St. Lawrence Cement
	17%	60	Fly Ash (C)	Lafarge - Great Lakes Fly Ash
Aggregate:	45%	1068	Stone	Lafarge Manitoulin
	55%	1290	Sand	Erie Sand and Gravel
Water:		100		
Admixtures:		240	ml/100kg of Cement - Rheomix 730fcs Water Reducer by Master Builders 65 ml/100 kg = 1 oz/100 lb 1 kg/m³ = 1.6855 lb/yd³	

APPENDIX B – CALIBRATION CERTIFICATES

1) ELE Soil Test Concrete Tester Certificate (2 pages)

2) FLUKE 743B Process Calibrator Certificate

PROCON

ENGINEERING INSPECTIONS INC.

P.O. BOX 119
INGLEWOOD, ONTARIO L0N 1K0

PHONE: (905) 838-2033
FAX: (905) 838-3761

CALIBRATION CERTIFICATE

This is to certify

that the testing equipment described below has been calibrated in accordance with the requirements of CSA Standard A23.2-9C and ASTM Standard E 4.

CUSTOMER: PRESTRESSED SYSTEMS INCORPARATED

ADDRESS: WALKER ROAD AT HWY. 401, WINDSOR, ONTARIO N9A 6M6

EQUIPMENT: ELE SOILTEST CONCRETE TESTER

SERIAL NUMBER: CT 7500 S/N 9805

CALIBRATION DATE: March 14, 2002

Machine Range	Loading Range
0 - 400,000 LBS	25,000 - 300,000 LBS

Load verification equipment calibrated in accordance with ASTM Standard E 74 and are directly traceable to the United States National Institute of Standards and Technology.

E.C. Shelestynsky, M.E.Sc., P.Eng.

PROCON

ENGINEERING INSPECTIONS INC.
CONSULTING ENGINEERS

P.O. BOX 119
Inglewood, Ontario
L0N 1K0

PHONE: (905) 838-2033
FAX: (905) 838-3761
CELLULAR: (416) 948-4782
e-mail: procon@aztec-net.com

CALIBRATION REPORT

CUSTOMER: PRESTRESSED SYSTEMS INCORPORATED
ADDRESS: WALKER ROAD AT HWY. 401, WINDSOR, ONTARIO
EQUIPMENT: ELE - ACCU-TEK COMPRESSION TESTER
SERIAL NUMBER: CT 7500 S/N 9805
CALIBRATION DATE: March 14, 2002

MACHINE READING LBS	LOAD CELL READING LBS	MACHINE ERROR LBS	MACHINE ERROR %	LOAD CELL
25,000	24,890	-110	0.44	B
40,000	39,860	-140	0.35	B
50,000	49,720	-280	0.56	B
75,000	74,700	-300	0.40	B
100,000	99,480	-520	0.52	B
150,000	149,100	-900	0.60	B
200,000	198,820	-1180	0.59	B
250,000	248,460	-1540	0.62	B
300,000	298,260	-1740	0.58	B

LOAD CELL READINGS ARE THE AVERAGE OF TWO OR MORE RUNS.

LOAD VERIFICATION EQUIPMENT

LOAD CELL NUMBER	SERIAL NUMBER	CAPACITY LBS	VERIFICATION DATE
A	138	50,000	2002-03-04
B	266 462 20	300,000	2002-03-04
C	CM508	500,000	2002-03-04

Load verification equipment calibrated in accordance with ASTM Standard E 74 and are directly traceable to the United States National Institute of Standards and Technology.

RECEIVED
MAR 25 2002

02/03/17
Date

E.C.Shelestynsky, M.E.Sc., P.Eng.

ACCUTECH RENTALS LTD.

INSTRUMENTATION AND SERVICE
#112, 9704 39 Ave. Edmonton, AB, T6E 6M7

Certificate of Calibration

For Instrument: FLUKE 743B

Description DOCUMENTING PROCESS CALIBRATOR

Asset Number: I-0694 **Serial Number** 7140610

Accutech Rentals Ltd. hereby certifies that...
the above described instrument met or exceeded all published specifications at the time of calibration specified below; and has been calibrated using standards whose accuracies are traceable to the National Institute of Standards and Technology (NIST) within the limitations of the Institute's calibration services, or have been derived from accepted values or physical constants, or have been derived by ratio or self calibration techniques. All calibration activities performed are in compliance with MIL-STD-45662A.

CALIBRATION INFORMATION

Cal Date Time 5/14/02 09:43:00 Temperature 23.00°C Shop
Next Cal Due 5/14/03 Humidity 60 % Work Order

Pass Y Tech Edwinzhang
Seals OK Y Note

Cal Procedure FLUKE 743: (1 YEAR) CAL VER /5500,3458 Revision $REVI

STANDARDS USED FOR CALIBRATION

Asset Number	Mfg	Model	Description	Cal. Date	Due Date
I-440	FLUKE	5500A	CALIBRATOR	8/ 1/01	8/ 1/02
I-759	HEWLETT PACKARD	3458A	SYSTEM MULTIMETER	6/ 6/01	6/ 6/02

Signed:

Fluke MET/CAL Run Time Report
File: rtcert01.rpt

APPENDIX C – EXPERIMENTAL RESULTS

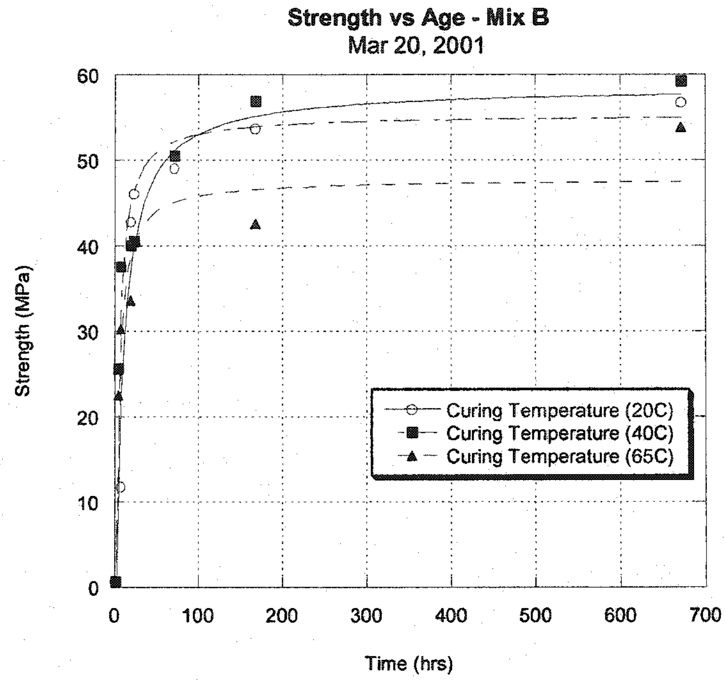
1) Strength vs Age Plots for Mix B and D

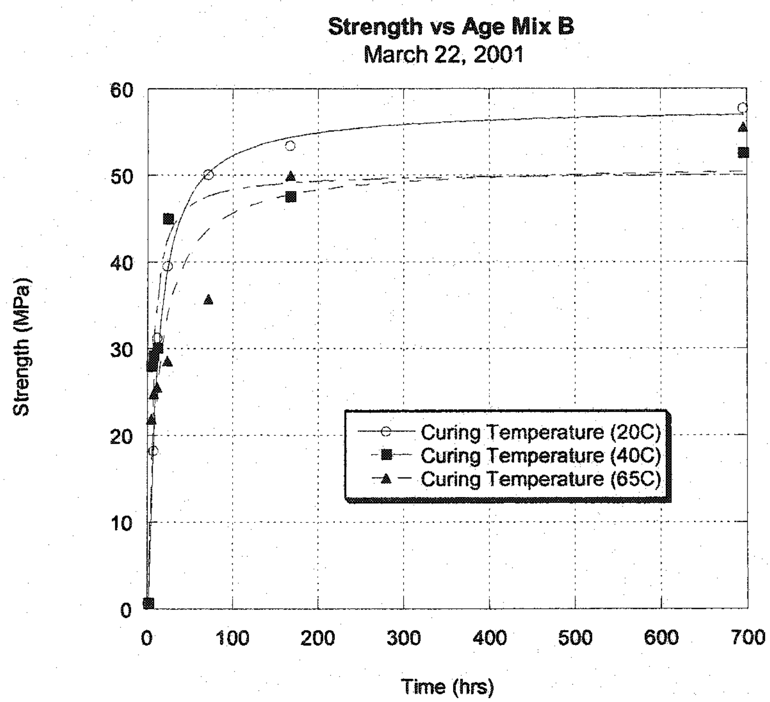
2) Tabulated Regression Analyses Results for Mixes B and D

3) Strength vs Maturity for each trial

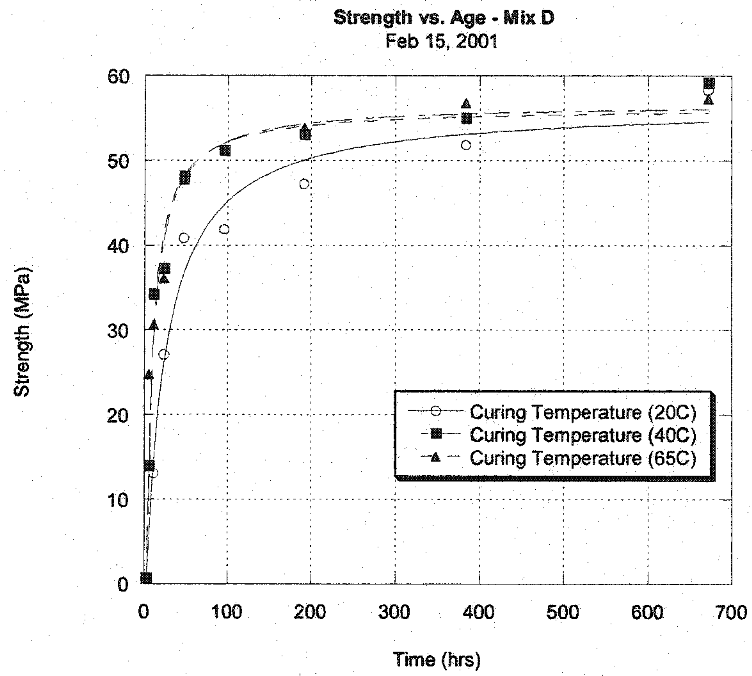
4) Relative Strength vs Maturity for all Mixes (combined trials)

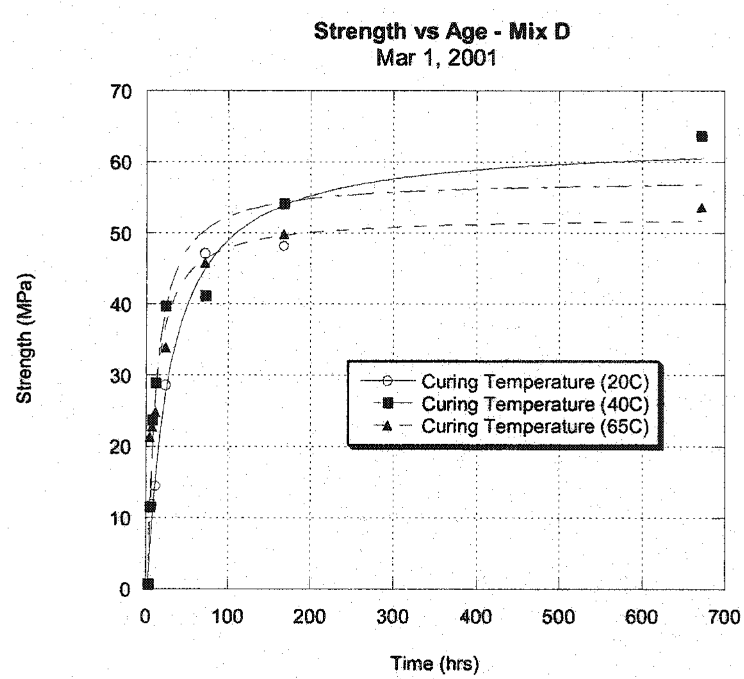
1) Strength vs Age Plot for Mix B





1) Strength vs Age Plot for Mix D

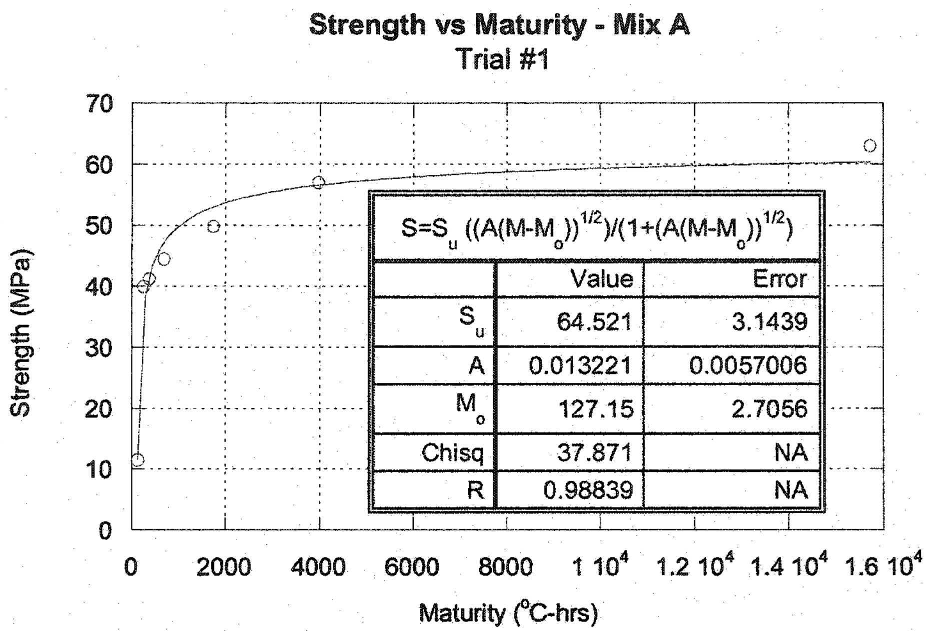


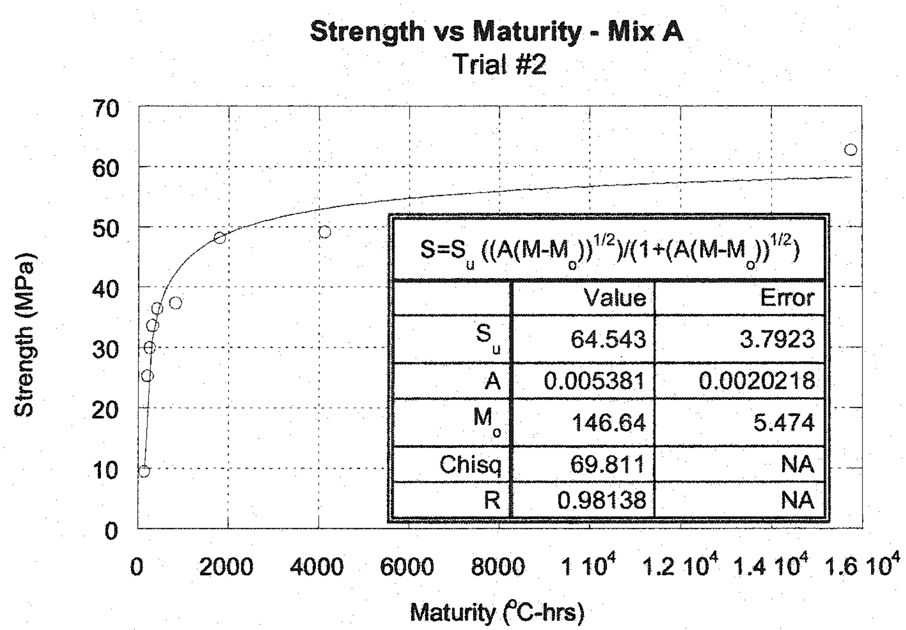


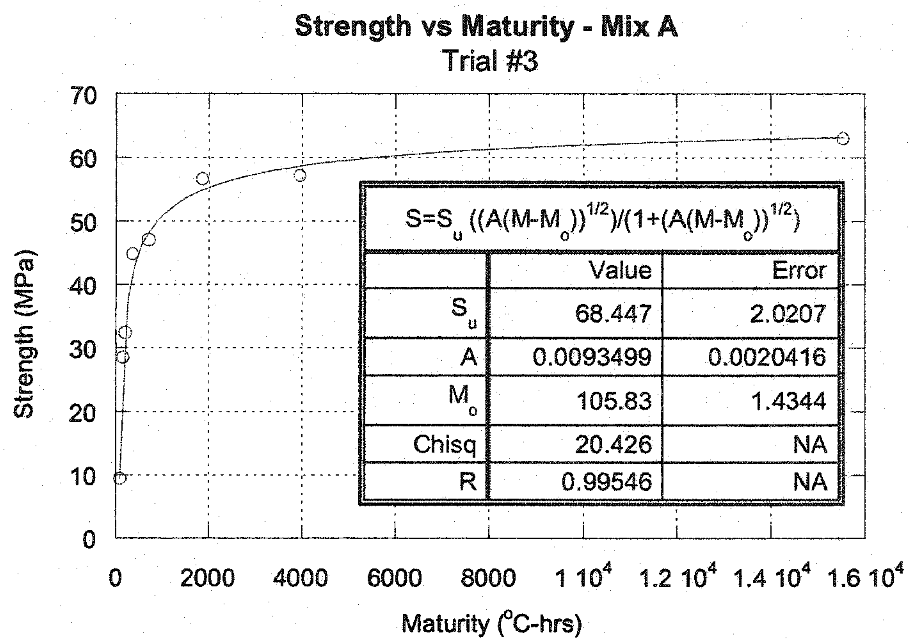
2) Tabulated Regression Analysis Results for Mixes B and D

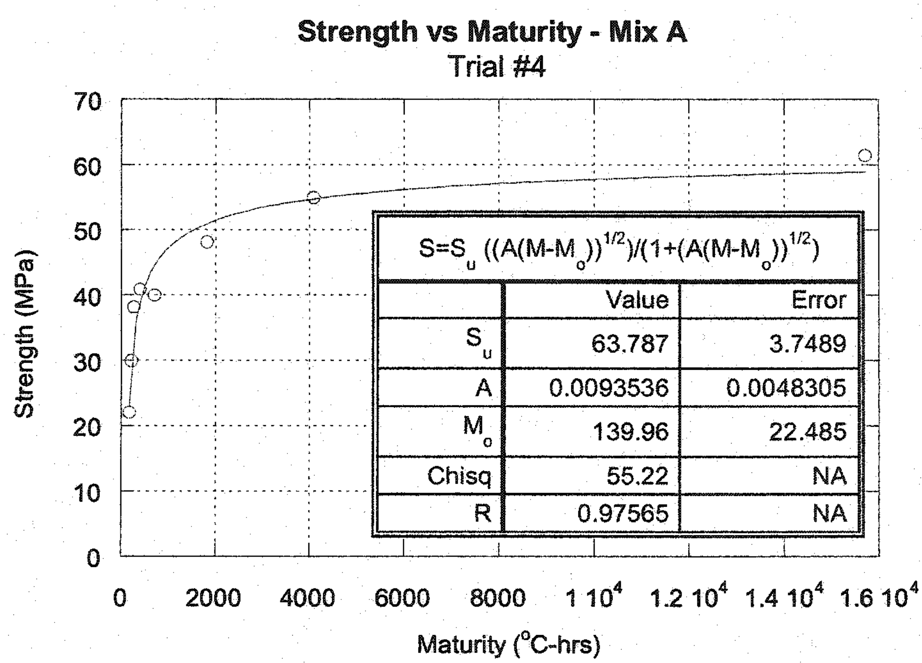
Plotted in Figures (8 and 9)			
Curing Temperature, T (°C)	Limiting Strength, Su (MPa)	Rate Constant, k (hr^{-1})	Intial Time, t_o (hr)
Mix B	March 20, 2001		
20	58.53	0.0995	2.29
40	55.32	0.2396	2.40
65	47.76	0.2446	1.87
Mix B	March 22, 2001		
20	57.84	0.0960	1.96
40	50.32	0.2541	1.85
65	51.30	0.0815*	0.06
		*not included	
Mix D	February 15, 2001		
20	56.55	0.0412	2.96
40	56.24	0.1121	2.92
65	56.72	0.1338	2.45
Mix D	March 1, 2001		
20	63.03	0.0360	2.46
40	57.60	0.1020	2.59
65	52.36	0.1112	1.89

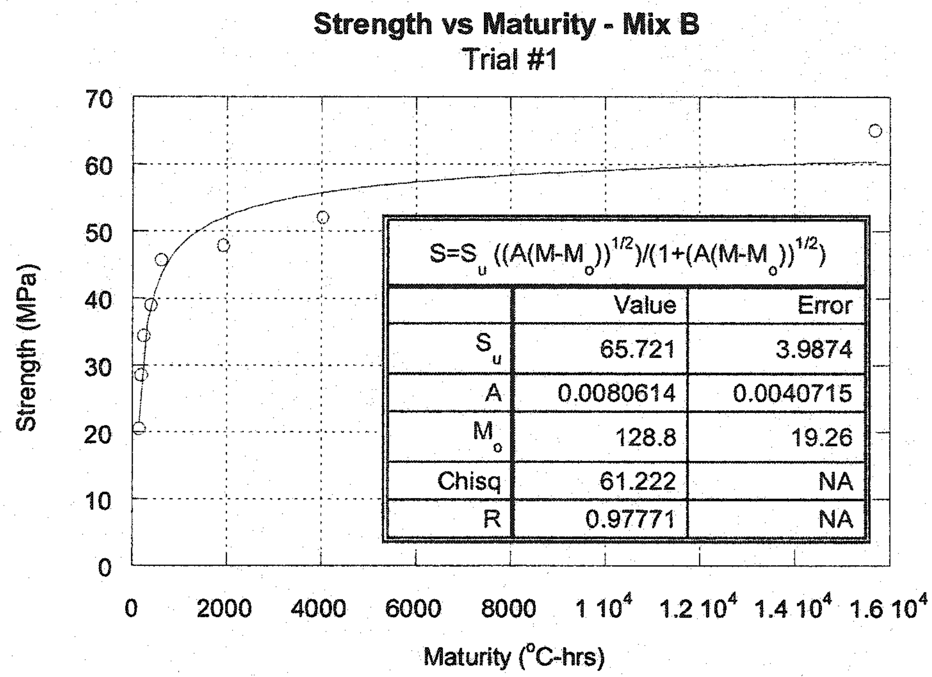
3) Strength vs Maturity for all Mixes (trial by trial)

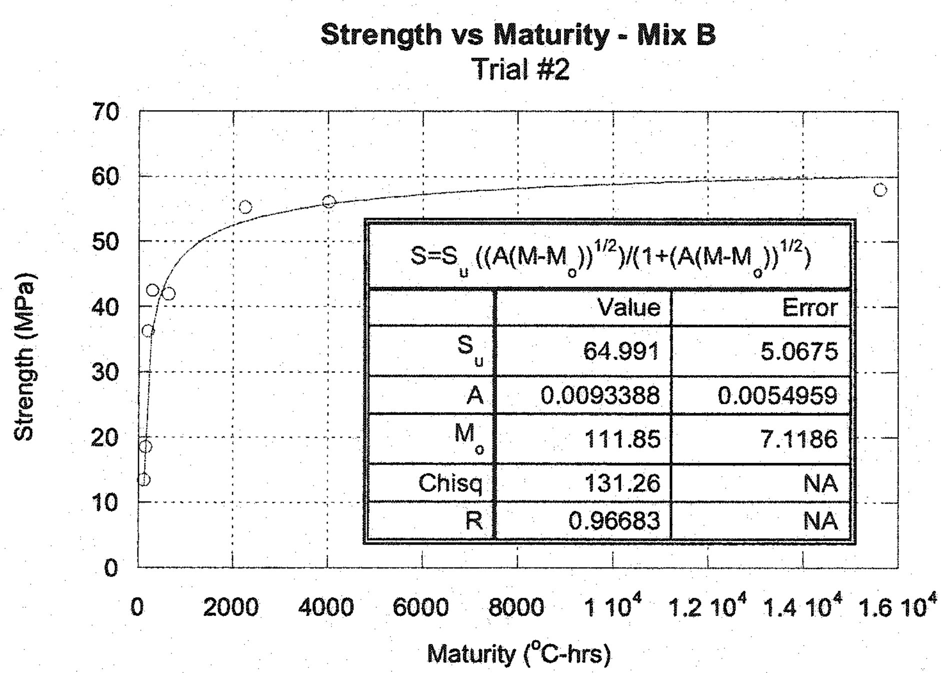


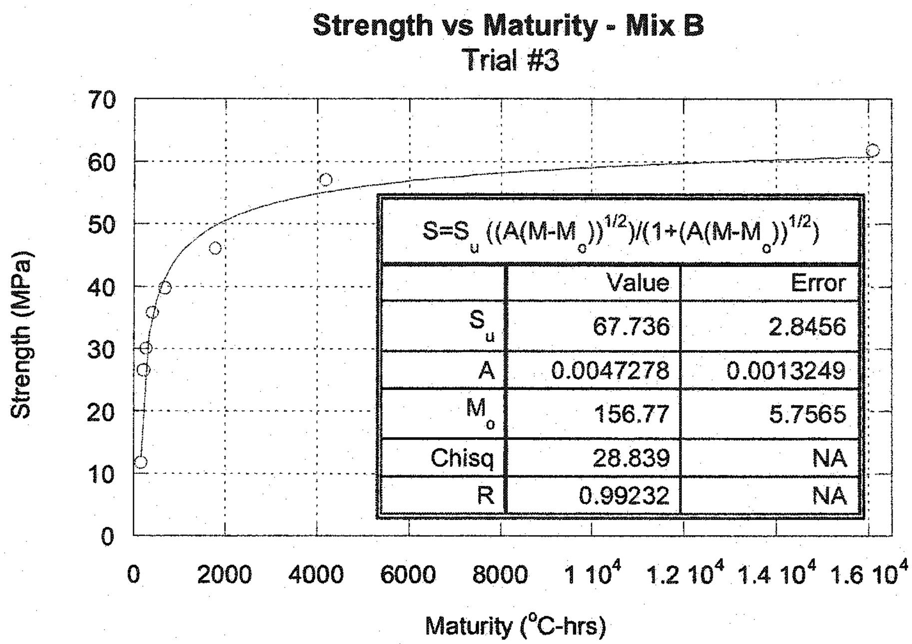


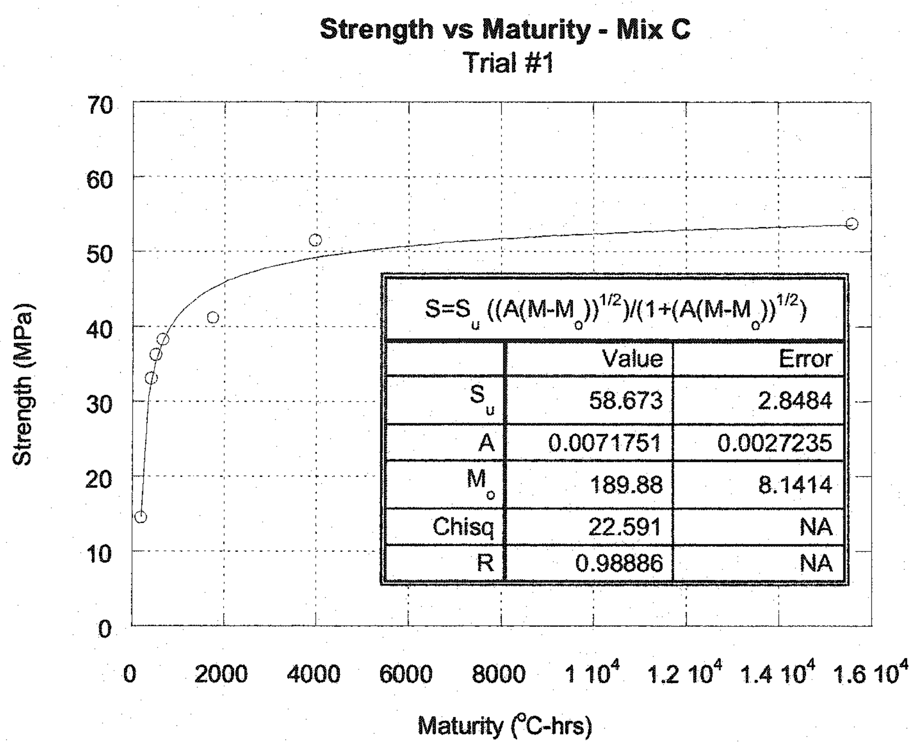

Strength vs Maturity - Mix A
Trial #3
Strength (MPa)
Maturity (°C-hrs)
0
10
20
30
40
50
60
70
0
2000
4000
6000
8000
1 10^4
1.2 10^4
1.4 10^4
1.6 10^4
S=S_u ((A(M-M_o))^1/2)/(1+(A(M-M_o))^1/2)
Value
Error
S_u 68.447 2.0207
A 0.0093499 0.0020416
M_o 105.83 1.4344
Chisq 20.426 NA
R 0.99546 NA


Strength vs Maturity - Mix A
Trial #4
Strength (MPa)
Maturity (°C-hrs)
0
10
20
30
40
50
60
70
0
2000
4000
6000
8000
1 10^4
1.2 10^4
1.4 10^4
1.6 10^4
S=S_u ((A(M-M_o))^1/2)/(1+(A(M-M_o))^1/2)
Value
Error
S_u 63.787 3.7489
A 0.0093536 0.0048305
M_o 139.96 22.485
Chisq 55.22 NA
R 0.97565 NA

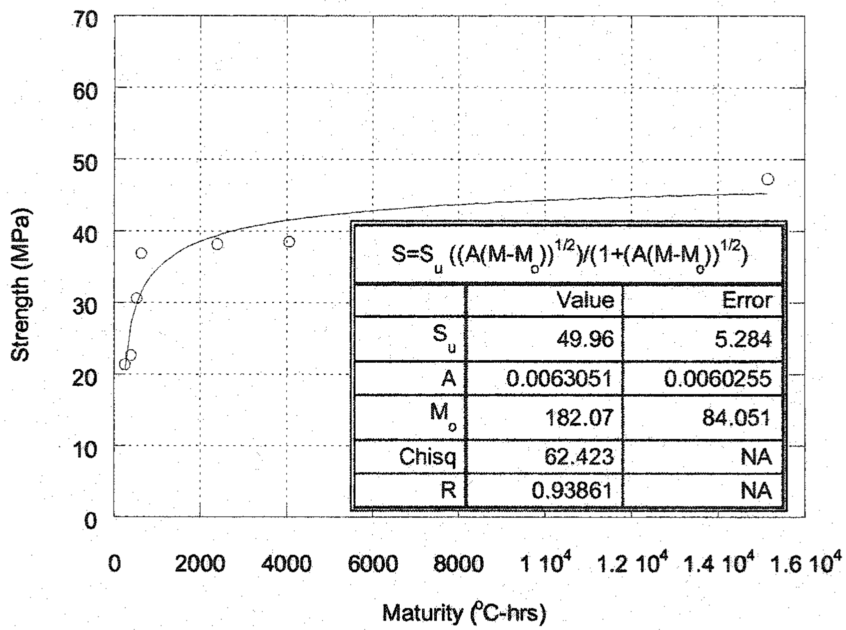

Strength vs Maturity - Mix B
Trial #1
S=S_u ((A(M-M_o))^1/2)/(1+(A(M-M_o))^1/2)
Value
Error
S_u 65.721 3.9874
A 0.0080614 0.0040715
M_o 128.8 19.26
Chisq 61.222 NA
R 0.97771 NA
Strength (MPa)
70
60
50
40
30
20
10
0
0
2000
4000
6000
8000
1 10^4
1.2 10^4
1.4 10^4
1.6 10^4
Maturity (°C-hrs)


Strength vs Maturity - Mix B
Trial #2
S=S_u ((A(M-M_o))^1/2)/(1+(A(M-M_o))^1/2)
Value
Error
S_u 64.991 5.0675
A 0.0093388 0.0054959
M_o 111.85 7.1186
Chisq 131.26 NA
R 0.96683 NA
Strength (MPa)
70
60
50
40
30
20
10
0
0
2000
4000
6000
8000
1 10^4
1.2 10^4
1.4 10^4
1.6 10^4
Maturity (°C-hrs)

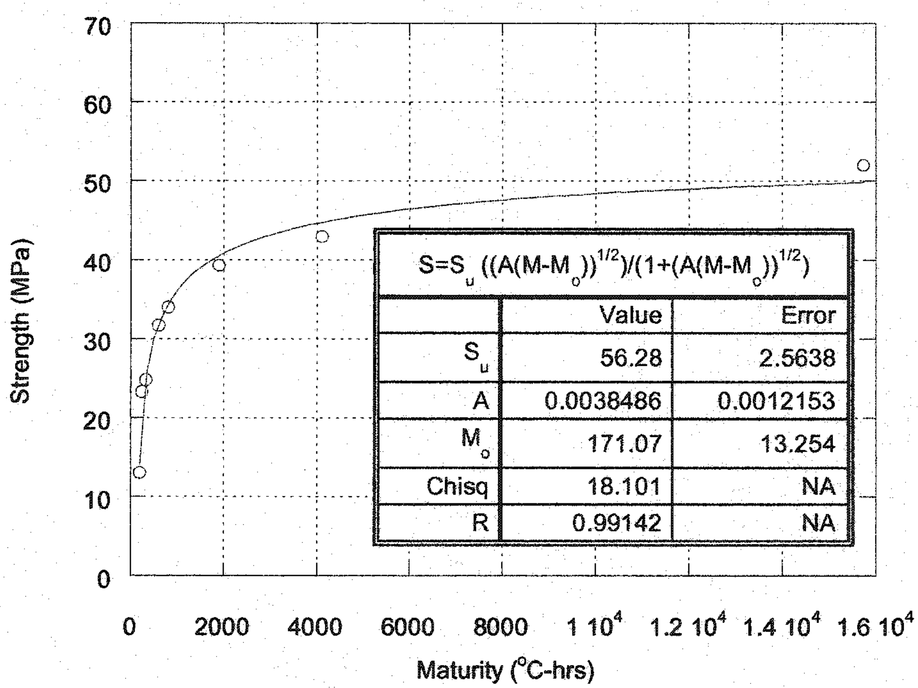

Strength vs Maturity - Mix B
Trial #3
Strength (MPa)
Maturity (°C-hrs)
0
10
20
30
40
50
60
70
0
2000
4000
6000
8000
1 10^4
1.2 10^4
1.4 10^4
1.6 10^4
S=S_u ((A(M-M_o))^1/2)/(1+(A(M-M_o))^1/2)
Value
Error
S_u 67.736 2.8456
A 0.0047278 0.0013249
M_o 156.77 5.7565
Chisq 28.839 NA
R 0.99232 NA

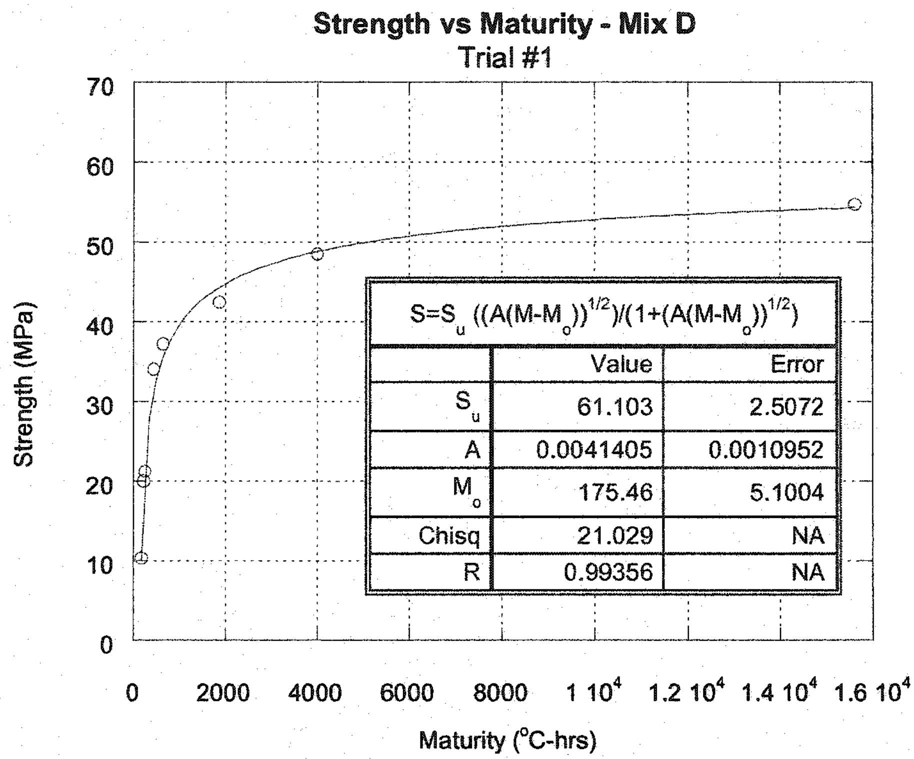

Strength vs Maturity - Mix C
Trial #1
Strength (MPa)
Maturity (°C-hrs)
0
10
20
30
40
50
60
70
0
2000
4000
6000
8000
1 10^4
1.2 10^4
1.4 10^4
1.6 10^4
S=S_u ((A(M-M_o))^1/2)/(1+(A(M-M_o))^1/2)
Value
Error
S_u 58.673 2.8484
A 0.0071751 0.0027235
M_o 189.88 8.1414
Chisq 22.591 NA
R 0.98886 NA

Strength vs Maturity - Mix C
Trial #2



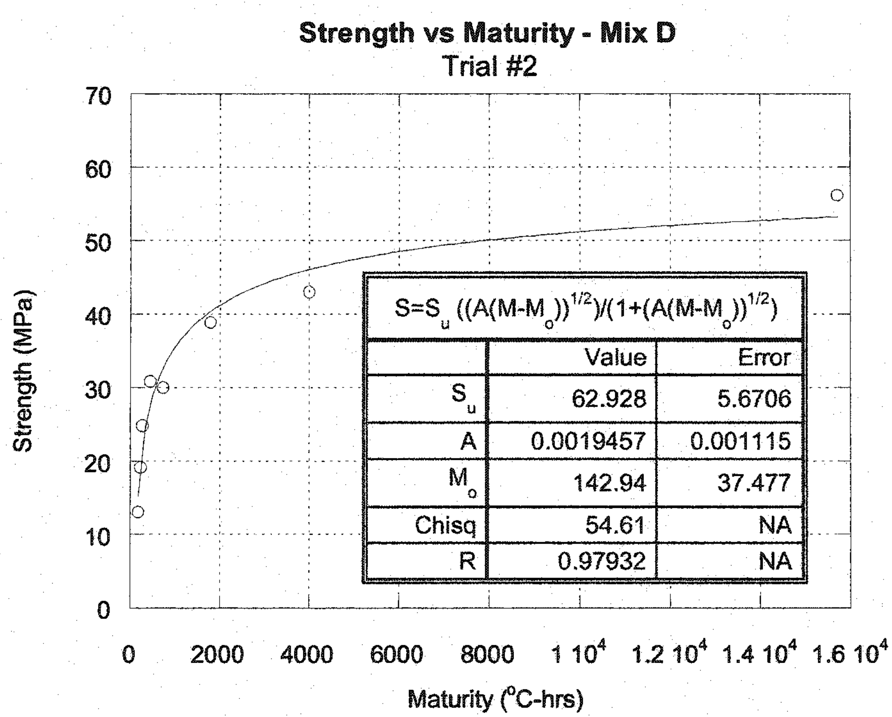
Strength vs Maturity - Mix C
Trial #3





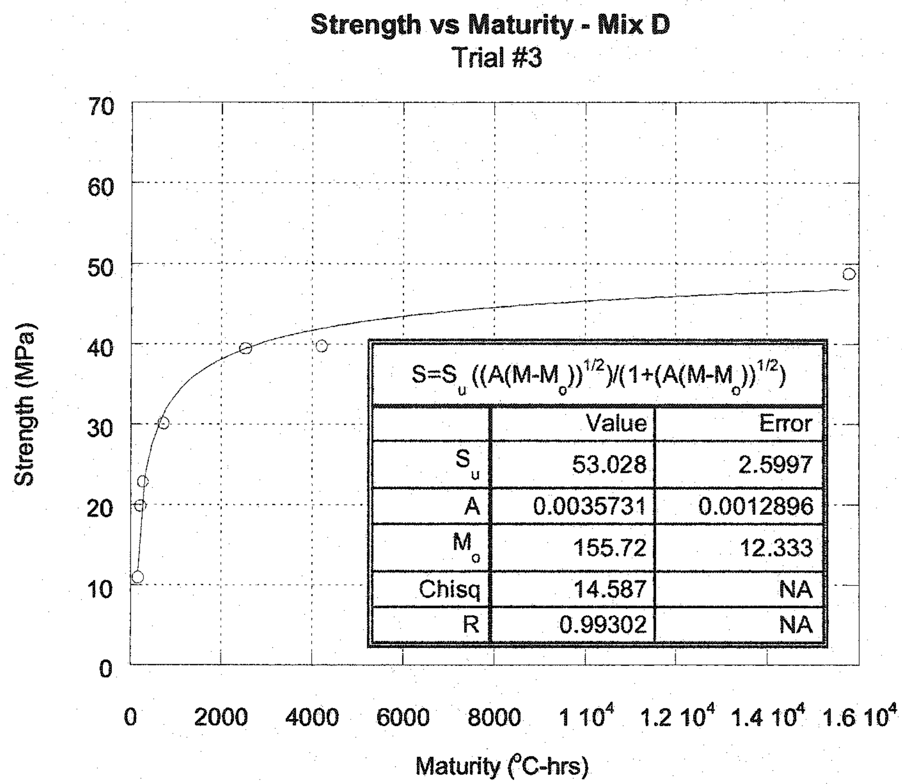
$S=S_u ((A(M-M_o))^{1/2})/(1+(A(M-M_o))^{1/2})$

	Value	Error
S_u	61.103	2.5072
A	0.0041405	0.0010952
M_o	175.46	5.1004
Chisq	21.029	NA
R	0.99356	NA



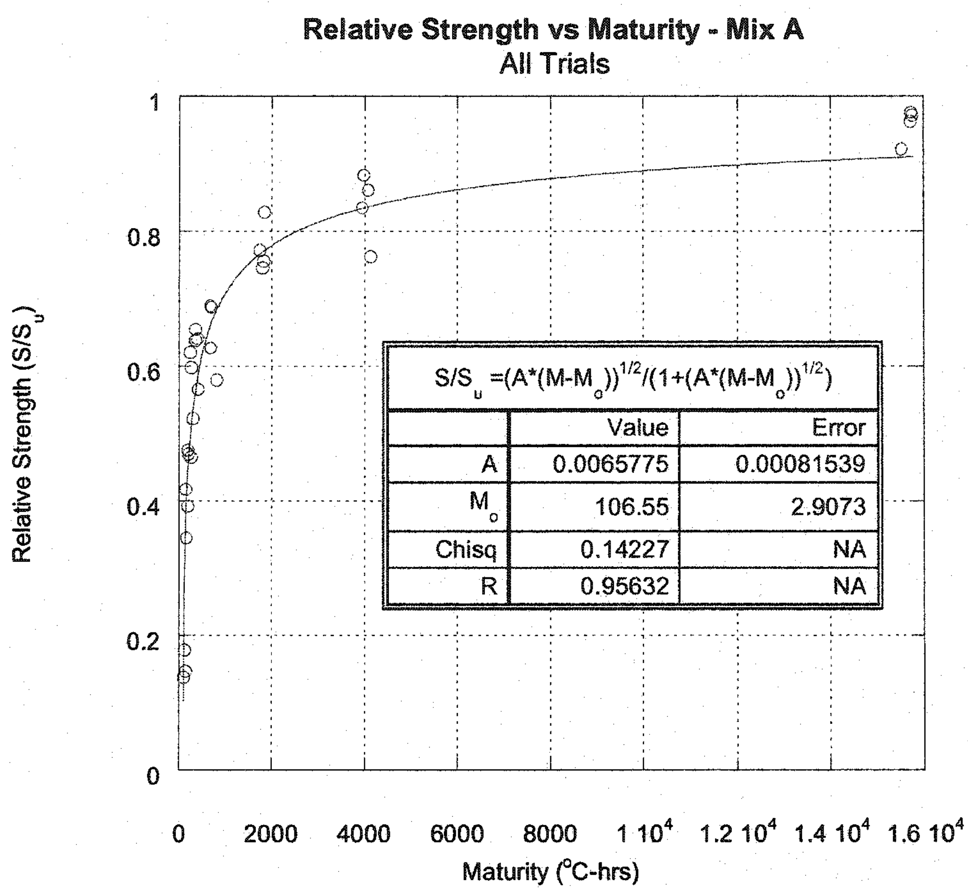
$S=S_u ((A(M-M_o))^{1/2})/(1+(A(M-M_o))^{1/2})$

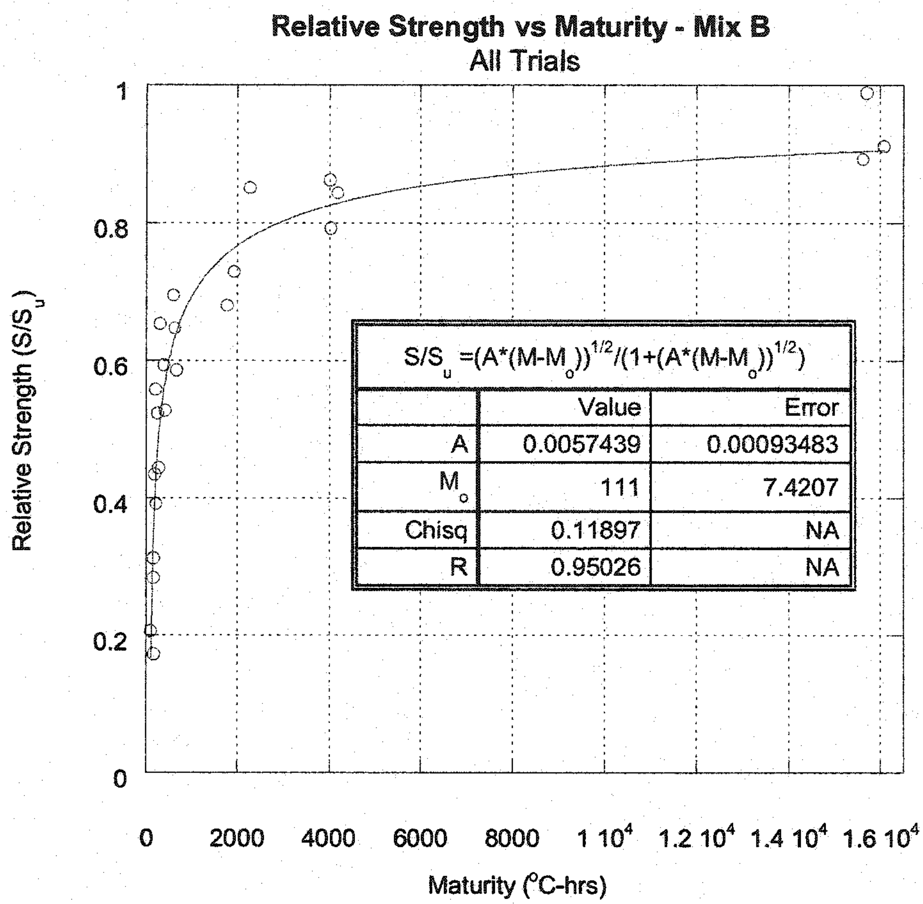
	Value	Error
S_u	62.928	5.6706
A	0.0019457	0.001115
M_o	142.94	37.477
Chisq	54.61	NA
R	0.97932	NA



	Value	Error
S_u	53.028	2.5997
A	0.0035731	0.0012896
M_o	155.72	12.333
Chisq	14.587	NA
R	0.99302	NA

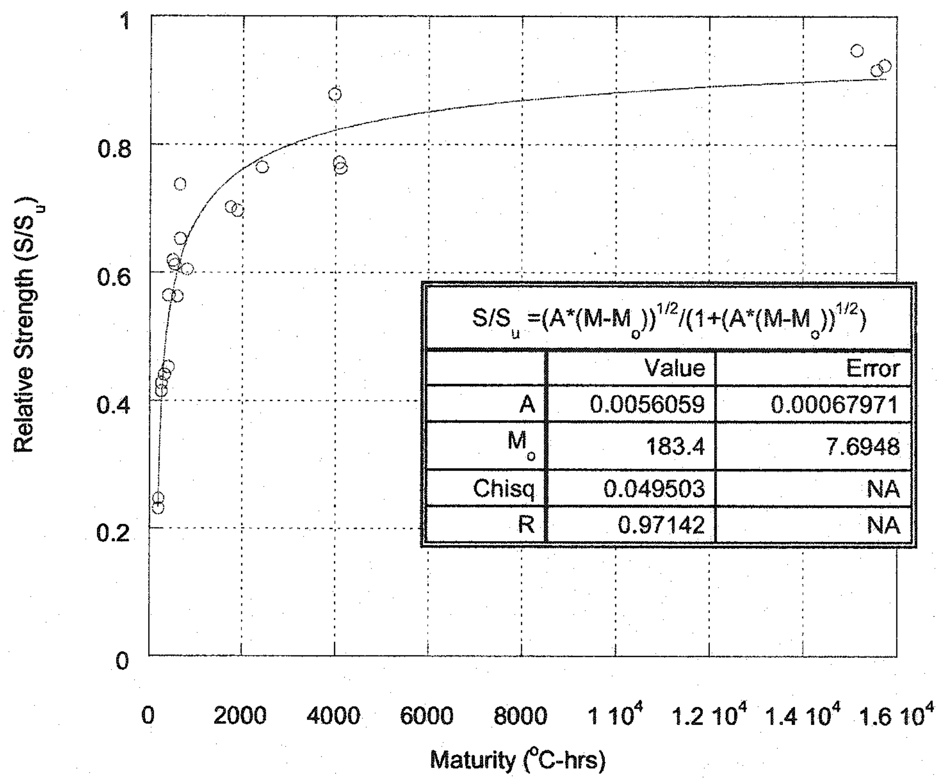
4) Relative Strength vs Maturity for all Mixes (combined trials)

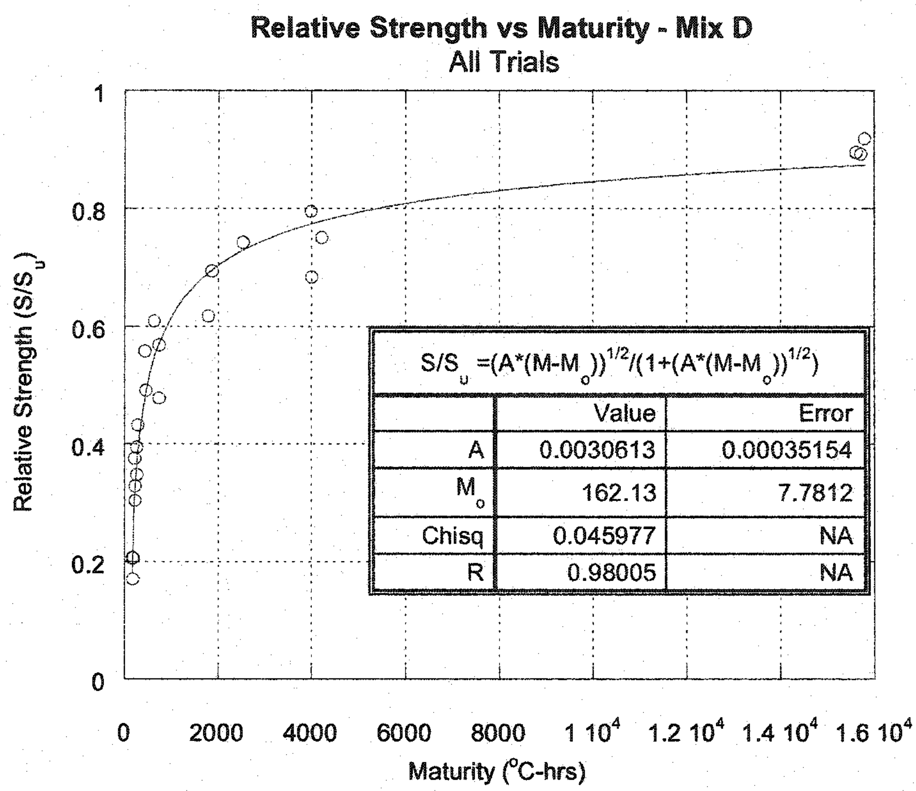




	Value	Error
A	0.0057439	0.00093483
M_o	111	7.4207
Chisq	0.11897	NA
R	0.95026	NA

Relative Strength vs Maturity - Mix C
All Trials





Relative Strength vs Maturity - Mix D
All Trials
Relative Strength (S/S_u)
Maturity (°C-hrs)
0
0.2
0.4
0.6
0.8
1
0
2000
4000
6000
8000
1 10^4
1.2 10^4
1.4 10^4
1.6 10^4
S/S_u =(A*(M-M_o))^1/2/(1+(A*(M-M_o))^1/2)
Value
Error
A
0.0030613
0.00035154
M_o
162.13
7.7812
Chisq
0.045977
NA
R
0.98005
NA

APPENDIX D – STRENGTH MATURITY RESULTS

1) Strength Age Data for each trial

2) Temperature Log Data and Calculated Maturity for each trial

Strength Age Data

Mix A
Trial 1

Test #: ___ 3 Date: _____ Feb 22/02 Bed #: _ 5

Time Batched: _____ 11:10am (D11:16:23) (21)
Time Extruded: ____ 11:25am
Time Samples cut: __ 12:30pm

Time 28-day in tank: _ 3:00pm
Time Bed Tarped: __ 12:30pm

Time Bed Untarped: 6:00pm
Concrete Temp.:___ 15 °C @ 11:40am

Mix Design: HC-1 1300-30 _____ -10 _____-FA

16.0107

Actual Quantities: (batch = 2 cuy)

Type 30	1286	lbs/2yd^3	381	kg/m^3	Hobo #	1A	in bed 12:30pm
Type 10	26	lbs/2yd^3	8	kg/m^3	Time laun.	11:08am	
FA	0	lbs/2yd^3	0	kg/m^3	Hobo #	1B	12:20pm
Sand	4385	lbs/2yd^3	1301	kg/m^3	Time laun.	11:08am	
Stone	3580	lbs/2yd^3	1062	kg/m^3			
730 fcs	52	oz/2yd^3	456	mL/m^3			

cylinder break:_4894 at 7.5 hrs

Ambient Temp.:____ 18 °C
Consistency: ______ Little wet

Sample ID	Test Age	Time	Time Extracted	Time in Tank	Tank Temp.	Core Size (L)	Core Size (L)	Density	Density	Strength	Average	Strength	Average	Type of break	StDev	Difference Ave. - Stren.	Included in Average	New Average
	(hr)	(at break)	(from bed)		(°C)	(mm)	(inches)	(pcf)	(kg/m^3)	(Mpa)	(Mpa)	(psi)	(psi)		(Mpa)	(Mpa)		(Mpa)
	4	3:40pm	3:30pm			101.6	4	151.6	2427	10.86		1574		c				
	4	3:40pm	3:30pm			98.4	3-7/8	150.2	2405	12.21	11.53	1771	1673	x				11.53
	7	6:13pm	6:00pm			101.6	4	151.6	2427	40.26		5837		x				
	7					101.6	4	151.6	2427	39.85	40.05	5778	5808	x				40.05
	12	11:00pm	6:00pm	7:00pm	23	101.6	4	150.1	2403	38.48		5579		c				
	12					88.9	3-1/2	-		43.92	41.20	6369	5974	x				41.20
	26	1:05pm			23	101.6	4	150.1	2403	42.35		6141		x				
	26					101.6	4	150.1	2403	46.72	44.53	6774	6458	x				44.53
3-3-A	72	11:00am			23	101.6	4	150.1	2403	49.42		7166		x				
3-3-B	72					101.6	4	150.1	2403	50.18	49.80	7276	7221	x				49.80
3-7-A	169	12:10pm			25	101.6	4	150.1	2403	59.19		8583		x				
3-7-B	169					101.6	4	150.1	2403	54.80	57.00	7946	8265	split				57.00
3-28-A	680	7:40pm			23	101.6	4	150.1	2403	64.28		9321		x				
3-28-B						101.6	4	150.1	2403	61.64	62.96	8938	9130	c				62.96
3-28S-A	680	7:40pm			23	101.6	4	153.1	2451	67.94		9851		x		2.28	x	
3-28S-B						101.6	4	154.6	2475	70.52		10225		x		-0.30		
3-28S-C						88.9	3-1/2	152.5	2442	71.66		10391		x		-1.44		
3-28S-D						88.9	3-1/2	155.9	2496	70.76	70.22	10260	10182	x	1.60	-0.54		70.98

x=conical break c=corner break s= vertical split breal

Temperature Log Data and Calculated Maturity						Limiting, Su	Mix	A
			10 min =	0.1666667	hours	64.52	Trial	1
Date	Time	Temp, T (C)	Age, t (min)	Age, t (hr)	Maturity, M (C-hrs)	Strength, S (MPa)	Relative, S/Su	
					0 datum			
time mixed	11:14:04	15	0	0.00	0			
2/22/2002	11:24:04	15	10	0.17	3			
2/22/2002	11:34:04	15	20	0.33	5			
2/22/2002	11:44:04	15	30	0.50	8			
2/22/2002	11:54:04	15	40	0.67	10			
2/22/2002	12:04:04	15	50	0.83	13			
2/22/2002	12:14:04	15	60	1.00	15			
2/22/2002	12:24:04	15	70	1.17	18			
2/22/2002	12:34:04	22	80	1.33	21			
2/22/2002	12:44:04	23	90	1.50	25			
2/22/2002	12:54:04	24	100	1.67	29			
2/22/2002	13:04:04	25	110	1.83	33			
2/22/2002	13:14:04	26	120	2.00	38			
2/22/2002	13:24:04	27	130	2.17	42			
2/22/2002	13:34:04	28	140	2.33	47			
2/22/2002	13:44:04	29	150	2.50	52			
2/22/2002	13:54:04	31	160	2.67	57			
2/22/2002	14:04:04	33	170	2.83	62			
2/22/2002	14:14:04	34	180	3.00	68			
2/22/2002	14:24:04	36	190	3.17	74			
2/22/2002	14:34:04	38	200	3.33	80			
2/22/2002	14:44:04	39	210	3.50	87			
2/22/2002	14:54:04	41	220	3.67	94			
2/22/2002	15:04:04	42	230	3.83	101			
2/22/2002	15:14:04	44	240	4.00	108			
2/22/2002	15:24:04	45	250	4.17	115			
2/22/2002	15:34:04	46	260	4.33	123			
2/22/2002	15:44:04	47	270	4.50	131	11.53	0.179	
2/22/2002	15:54:04	49	280	4.67	139			
2/22/2002	16:04:04	50	290	4.83	147			
2/22/2002	16:14:04	51	300	5.00	156			
2/22/2002	16:24:04	51	310	5.17	164			
2/22/2002	16:34:04	52	320	5.33	173			
2/22/2002	16:44:04	53	330	5.50	182			
2/22/2002	16:54:04	53	340	5.67	191			
2/22/2002	17:04:04	53	350	5.83	200			
2/22/2002	17:14:04	53	360	6.00	208			
2/22/2002	17:24:04	53	370	6.17	217			
2/22/2002	17:34:04	52	380	6.33	226			
2/22/2002	17:44:04	52	390	6.50	235			
2/22/2002	17:54:04	52	400	6.67	243			
untarped	18:04:04	50	410	6.83	252			
2/22/2002	18:14:04	48	420	7.00	255	40.05	0.621	
		23	430	12.00	370	41.20	0.639	
		23	440	26.00	692	44.53	0.690	
		23	450	72.00	1750	49.80	0.772	
		23	460	169.00	3981	57.00	0.883	
		23	470	680.00	15734	62.96	0.976	

Strength Age Data

Mix A
Trial 2

Test #: 4 Date: Feb 25/02 Bed #: 2

Time Batched: 11:15am (D11:19:22) (20)
Time Extruded: 11:35am
Time Samples cut: 12:10pm

Time 28-day in tank: 3:15pm
Time Bed Tarped: 12:25pm

Time Bed Untarped: 6:10pm
Concrete Temp.: 25°C @ 11:35am
24@12:17pm
Ambient Temp.: 25°C @ 11:35am
Consistency: Normal

Mix Design: HC-1 1300-30 ____ -10 ____-FA
Actual Quantities: (batch = 2 cuy)

							In bed
Type 30	1292	lbs/2yd³	383	kg/m³	Hobo #	1A	12:15pm
Type 10	10	lbs/2yd³	3	kg/m³	Time laun.	11:41am	
FA	0	lbs/2yd³	0	kg/m³	Hobo #	1B	12:15pm
Sand	4395	lbs/2yd³	1304	kg/m³	Time laun.	11:41am	
Stone	3595	lbs/2yd³	1066	kg/m³			
730 fcs	52	oz/2yd³	456	mL/m³	cylinder break: 4079 at 6.5 hrs		

Sample ID	Test Age	Time	Time Extracted	Time In Tank	Tank Temp.	Core Size (L)	Core Size (L)	Density	Density	Strength	Average	Strength	Average	Type of break	StDev	Difference Ave. - Stren.	Not Included in Average	New Average
	(hr)	(at break)	(from bed)		(°C)	(mm)	(inches)	(kg/m³)	(pcf)	(Mpa)	(Mpa)	(psi)	(psi)		(Mpa)	(Mpa)		(Mpa)
	4	3:30pm	3:15pm		22	101.6	4	2357	147.1	9.90		1435		x				
	4					101.6	4	2381	148.6	9.01	9.46	1307	1371	x				9.46
	5	4:30pm	4:15pm			98.425	3-7/8	2406	150.2	25.66		3721		split		0.38		
	5					101.6	4	2405	150.1	24.68		3579		x		1.36		
	5	4:35pm				101.6	4	2405	150.1	25.59		3711		x		0.45		
	5	4:40pm				101.6	4	2381	148.6	28.25	26.05	4096	3777	skewed	1.53	-2.20	x	25.31
	6	5:30pm	6;15pm		23	101.6	4	2381	148.6	30.08		4362		x		0.00		
	6					95.25	3-3/4	2409	150.4	29.15		4227		x		0.93	x	
	6					95.25	3-3/4	2384	148.8	29.94		4341		x		0.15		
	6					88.9	3-1/2	2331	145.5	31.17	30.09	4520	4363	x	0.83	-1.09	x	30.01
	7	6:45pm	6:15pm		24	101.6	4	2405	150.1	28.58		4144		x		3.86	x	
	7					101.6	4	2429	151.6	34.70		5032		x		-2.26		
	7	6:50pm				101.6	4	2429	151.6	35.03		5080		x		-2.59		
	7	6:53pm				88.9	3-1/2			31.44	32.44	4559	4704	x	3.04	1.00		33.73
	12	11:15pm	6:30pm	7:30pm		98.425	3-7/8	2406	150.2	32.48		4709		x		3.99	x	
	12					101.6	4	2381	148.6	37.17		5390		x		-0.70		
	12					98.425	3-7/8	2382	148.7	35.90		5205		x		0.57		
	12					88.9	3-1/2	2443	152.5	40.33	36.47	5848	5288	x	3.25	-3.86	x	36.53
	29.5	4:45pm			22	101.6	4	2405	150.1	36.71		5323		x		1.70		
	29.5					101.6	4	2429	151.6	41.28		5985		x		-2.87	x	
	29.5					101.6	4	2429	151.6	36.65		5314		x		1.76		
	29.5					101.6	4	2477	154.6	39.01	38.41	5656	5570	x	2.20	-0.60		37.46
4-3-A	72				22	101.6	4	2429	151.6	49.92		7238		x				
4-3-B	72					101.6	4	2405	150.1	46.41	48.16	6729	6984	x				48.16
4-7-A	173	4:30pm			14	101.6	4	2405	150.1	42.48		6160		c	*Bad Break - not included			
4-7-B						101.6	4	2429	151.6	49.21	49.21	7136	7136	x				49.21
4-28-A	679	6:05pm			23	101.6	4	2453	153.1	63.39		9192		s				
4-28-B						101.6	4	2429	151.6	62.13	62.76	9009	9101	x				62.76
4-28S-A	679	6:05pm	12:15pm	3:00pm	23	101.6	4	2464	153.8	73.04		10591		x				
4-28S-B			12:15pm	3:00pm		101.6	4	2432	151.8	63.86	68.45	9259	9925	x				68.45

x=conical break c=corner break s= vertical split break

Temperature Log Data and Calculated Maturity						Limiting, Su	Mix	A
			10 min =	0.16667	hours	64.54	Trial	2
Date	Time	Temp, T (C)	Age, t (min)	Age, t (hr)	Maturity, M (C-hrs)	Strength, S (MPa)	Relative, S/Su	
					0 datum			
time mixed	11:11	25	0	0.00	0			
	11:21	25	10	0.17	4			
	11:31	25	20	0.33	8			
2/25/2002	11:41:25	25	30	0.50	13			
2/25/2002	11:51:25	25	40	0.67	17			
2/25/2002	12:01:25	25	50	0.83	21			
2/25/2002	12:11:25	25	60	1.00	25			
2/25/2002	12:21:25	27	70	1.17	30			
2/25/2002	12:31:25	27	80	1.33	34			
2/25/2002	12:41:25	28	90	1.50	39			
2/25/2002	12:51:25	30	100	1.67	44			
2/25/2002	13:01:25	30	110	1.83	49			
2/25/2002	13:11:25	31	120	2.00	54			
2/25/2002	13:21:25	33	130	2.17	59			
2/25/2002	13:31:25	35	140	2.33	65			
2/25/2002	13:41:25	37	150	2.50	71			
2/25/2002	13:51:25	38	160	2.67	78			
2/25/2002	14:01:25	40	170	2.83	84			
2/25/2002	14:11:25	41	180	3.00	91			
2/25/2002	14:21:25	42	190	3.17	98			
2/25/2002	14:31:25	43	200	3.33	105			
2/25/2002	14:41:25	44	210	3.50	113			
2/25/2002	14:51:25	45	220	3.67	120			
2/25/2002	15:01:25	47	230	3.83	128			
2/25/2002	15:11:25	48	240	4.00	136			
2/25/2002	15:21:25	50	250	4.17	144			
2/25/2002	15:31:25	51	260	4.33	153	9.46	0.147	
2/25/2002	15:41:25	53	270	4.50	162			
2/25/2002	15:51:25	55	280	4.67	171			
2/25/2002	16:01:25	55	290	4.83	180			
2/25/2002	16:11:25	56	300	5.00	189			
2/25/2002	16:21:25	57	310	5.17	199			
2/25/2002	16:31:25	57	320	5.33	208	25.31	0.392	
2/25/2002	16:41:25	58	330	5.50	218			
2/25/2002	16:51:25	58	340	5.67	228			
2/25/2002	17:01:25	58	350	5.83	237			
2/25/2002	17:11:25	58	360	6.00	247			
2/25/2002	17:21:25	59	370	6.17	257			
2/25/2002	17:31:25	60	380	6.33	267	30.01	0.465	
2/25/2002	17:41:25	60	390	6.50	277			
2/25/2002	17:51:25	60	400	6.67	287			
2/25/2002	18:01:25	58	410	6.83	297			
untarped	18:11:25	56	420	7.00	306			
2/25/2002	18:21:25	53	430	7.17	315			
2/25/2002	18:31:25	49	440	7.33	323	33.73	0.523	
		23	450	7.50	327			
		23	460	12.00	430	36.53	0.566	
		23	470	29.50	833	37.46	0.580	
		23	480	72.00	1810	48.16	0.746	
		23	490	173.00	4133	49.21	0.763	
		23	500	679.00	15771	62.76	0.972	

Strength Age Data

Mix A
Trial 3

Test #: 5 Date: Feb 27/02 Bed #: 3

Time Batched: 11:10am (D11:17:50) (1)
Time Extruded: 11:30am
Time Samples cut: 11:35pm

Time 28-day in tank: 4:30pm
Time Bed Tarped: 12:30pm

Time Bed Untarped:
Concrete Temp.: 17°C @ 11:34am

Ambient Temp.: 17°C @ 11:43am
Consistency: Normal

Mix Design: HC-1 1300-30 ____ -10 ____-FA
Actual Quantities: (batch = 2 cuy)

							in bed
Type 30	1274	lbs/2yd³	378	kg/m³	Hobo #	1A	11:43pm
Type 10	46	lbs/2yd³	14	kg/m³	Time laun.	11:25am	
FA	0	lbs/2yd³	0	kg/m³	Hobo #	1B	11:43pm
Sand	4380	lbs/2yd³	1299	kg/m³	Time laun.	11:25am	
Stone	3585	lbs/2yd³	1063	kg/m³			
730 fcs	52	oz/2yd³	456	mL/m³	cylinder break: at 6.5 hrs		

Sample ID	Test Age	Time	Time Extracted	Time in Tank	Tank Temp.	Core Size (L)	Core Size (L)	Density	Density	Strength	Average	Strength	Average	Type of break	StDev	Difference Ave. - Stren.	Not Included in Average	New Average
	(hr)	(at break)	(from bed)		(°C)	(mm)	(inches)	(kg/m³)	(pcf)	(Mpa)	(Mpa)	(psi)	(psi)		(Mpa)	(Mpa)		(Mpa)
	4	3:25pm	3:12pm		22	98.4	3-7/8	2432	151.8	8.74		1268		x				
	4					101.6	4	2381	148.6	10.13	9.44	1469	1369	x				9.44
	5	4:30pm	4:14pm		22	101.6	4	2381	148.6	26.23		3803		x		1.23		
	5					101.6	4	2381	148.6	24.22		3512		x		3.24	x	
	5					101.6	4	2429	151.6	29.68		4303		x		-2.22		
	5					101.6	4	2429	151.6	29.71	27.46	4308	3982	x	2.71	-2.25		28.54
	6	5:30pm	5:13pm		22	101.6	4	2429	151.6	31.88		4623		x		1.19		
	6					101.6	4	2429	151.6	33.80		4901		x		-0.72		
	6					101.6	4	2429	151.6	34.74		5037		split		-1.66	x	
	6					101.6	4	2429	151.6	31.88	33.08	4623	4796	x	1.43	1.19		32.52
5-12-A	12	11:45pm	6:18pm	7:00pm	23	101.6	4	2429	151.6	45.36		6577		x		-1.29		
5-12-B	12					101.6	4	2453	153.1	43.41		6294		x		0.66		
5-12-C	12					101.6	4	2453	153.1	41.86		6070		x		2.21	x	
5-12-D	12					101.6	4	2453	153.1	45.66	44.07	6620	6390	x	1.78	-1.58		44.81
5-24-A	27	2:10pm			22	101.6	4	2429	151.6	47.97		6955		x		-0.48		
5-24-B	27					101.6	4	2429	151.6	44.42		6441		x		3.06	x	
5-24-C	27					101.6	4	2453	153.1	51.29		7437		x		-3.81	x	
5-24-D	27					101.6	4	2429	151.6	46.26	47.48	6708	6885	x	2.92	1.22		47.11
5-3-A	77	4:00pm			20	101.6	4	2429	151.6	46.57		6752		x		7.62	x	
5-3-B	77					101.6	4	2453	153.1	53.15		7707		x		1.03		
5-3-C	77					101.6	4	2453	153.1	59.29		8597		x		-5.11		
5-3-D	77					101.6	4	2453	153.1	57.72	54.18	8369	7856	x	5.71	-3.54		56.72
5-7-A	168	12:15pm	9:15pm	9:30pm		98.4	3-7/8	2457	153.4	55.36		8027		x		-0.43		
5-7-B	168					98.4	3-7/8	2382	148.7	48.34		7009		c		6.59	x	
5-7-C	168					98.4	3-7/8	2432	151.8	57.83		8385		x		-2.90		
5-7-D	168					98.4	3-7/8	2432	151.8	58.19	54.93	8438	7965	x	4.57	-3.26		57.13
5-28-A	672					98.4	3-7/8	2457	153.4	61.70		8947		x		1.18		
5-28-B	672					98.4	3-7/8	2432	151.8	55.78		8088		c		7.10	x	
5-28-C	672					98.4	3-7/8	2432	151.8	69.57		10087		x		-6.69	x	
5-28-D	672					98.4	3-7/8	2432	151.6	64.47	62.88	9348	9118	x	5.75	-1.59		63.09
5-28S-A	672		11:40am	4:30pm		101.6	4	2429	151.6	68.74		9967		x		0.30		
5-28S-B	672					101.6	4	2453	153.1	76.04		11026		x		-7.00	x	
5-28S-C	672					101.6	4	2429	151.6	68.49		9931		x		0.55		
5-28S-D	672					101.6	4	2405	150.1	62.89	69.04	9119	10011	x	5.39	6.15	x	68.61

x=conical break c=corner break s= vertical split break

Temperature Log Data and Calculated Maturity						Limiting, Su	Mix	A
			10 min =	0.16667	hours	68.45	Trial	3
Date	Time	Temp, T (C)	Age, t (min)	Age, t (hr)	Maturity, M (C-hrs)	Strength, S (MPa)	Relative, S/Su	
					0 datum			
time mixed	11:13	19	0	0.00	0			
2/27/2002	11:23:53	19	10	0.17	3			
2/27/2002	11:33:53	19	20	0.33	6			
2/27/2002	11:43:53	19	30	0.50	10			
2/27/2002	11:53:53	19	40	0.67	13			
2/27/2002	12:03:53	19	50	0.83	16			
2/27/2002	12:13:53	19	60	1.00	19			
2/27/2002	12:23:53	19	70	1.17	22			
2/27/2002	12:33:53	19	80	1.33	25			
2/27/2002	12:43:53	19	90	1.50	29			
2/27/2002	12:53:53	20	100	1.67	32			
2/27/2002	13:03:53	20	110	1.83	35			
2/27/2002	13:13:53	22	120	2.00	39			
2/27/2002	13:23:53	23	130	2.17	43			
2/27/2002	13:33:53	24	140	2.33	47			
2/27/2002	13:43:53	26	150	2.50	51			
2/27/2002	13:53:53	27	160	2.67	56			
2/27/2002	14:03:53	28	170	2.83	60			
2/27/2002	14:13:53	30	180	3.00	65			
2/27/2002	14:23:53	32	190	3.17	71			
2/27/2002	14:33:53	33	200	3.33	76			
2/27/2002	14:43:53	35	210	3.50	82			
2/27/2002	14:53:53	37	220	3.67	88			
2/27/2002	15:03:53	39	230	3.83	95			
2/27/2002	15:13:53	41	240	4.00	101			
2/27/2002	15:23:53	43	250	**4.17**	**109**	**9.44**	**0.138**	
2/27/2002	15:33:53	45	260	4.33	116			
2/27/2002	15:43:53	46	270	4.50	124			
2/27/2002	15:53:53	47	280	4.67	132			
2/27/2002	16:03:53	49	290	4.83	140			
2/27/2002	16:13:53	50	300	5.00	148			
2/27/2002	16:23:53	51	310	5.17	157			
2/27/2002	16:33:53	51	320	**5.33**	**165**	**28.54**	**0.417**	
2/27/2002	16:43:53	51	330	5.50	174			
2/27/2002	16:53:53	50	340	5.67	182			
2/27/2002	17:03:53	49	350	5.83	190			
2/27/2002	17:13:53	50	360	6.00	198			
2/27/2002	17:23:53	49	370	6.17	207			
2/27/2002	17:33:53	49	380	**6.33**	**215**	**32.52**	**0.475**	
2/27/2002	17:43:53	48	390	6.50	223			
2/27/2002	17:53:53	48	400	6.67	231			
2/27/2002	18:03:53	48	410	6.83	239			
2/27/2002	18:13:53	48	420	7.00	247			
untarped	18:23:53	47	430	7.17	255			
2/27/2002		23	440	**12.00**	**366**	**44.81**	**0.655**	
		23	450	**27.00**	**711**	**47.11**	**0.688**	
		23	460	**77.00**	**1861**	**56.72**	**0.829**	
		23	470	**168.00**	**3954**	**57.13**	**0.835**	
		23	480	**672.00**	**15546**	**63.09**	**0.922**	

Strength Age Data

Mix A
Trial 4

Test #: ___ 7   Date: ___ March 5/02   Bed #: _ 3

Time Batched: ______ 10:45am (D10:51:11) (22)
Time Extruded: _____ 11:10am
Time Samples cut: __ 12:10pm

Time 28-day in tank: _ 3:30pm
Time Bed Tarped: ___ 12:15pm

Time Bed Untarped: 5:45pm
Concrete Temp.:_____ 17°C @ 11:16am

Mix Design: HC-1 1300-30 _____ -10 _____-FA
Actual Quantities: (batch = 2 cuy)

							in bed
Type 30	1332	lbs/2yd³	395	kg/m³	Hobo #	1A	12:15pm
Type 10	0	lbs/2yd³	0	kg/m³	Time laun.		
FA	0	lbs/2yd³	0	kg/m³	Hobo #	1B	12:15pm
Sand	4385	lbs/2yd³	1301	kg/m³	Time laun.		
Stone	3585	lbs/2yd³	1063	kg/m³			
730 fcs	52	oz/2yd³	456	mL/m³			

cylinder break:_4209 and 3969 psi at 6 hrs

Ambient Temp.:_____ 15°C @ 11:15am
Consistency: _______ Normal

Sample ID	Test Age	Time	Time Extracted	Time in Tank	Tank Temp.	Core Size (L)	Core Size (L)	Density	Density	Strength	Average	Strength	Average	Type of break	StDev	Difference Ave. - Stren.	Included in Average	New Average
	(hr)	(at break)	(from bed)		(°C)	(mm)	(inches)	(kg/m³)	(pcf)	(Mpa)	(Mpa)	(psi)	(psi)		(Mpa)	(Mpa)		(Mpa)
	5	3:45pm	3:25pm		22	101.6	4	2405	150.1	23.12		3353		x		-1.03	x	
	5					101.6	4	2381	148.6	21.79		3159		x		0.31		
	5					101.6	4	2405	150.1	21.27		3084		x		0.83	x	
	5					101.6	4	2405	150.1	22.21	22.10	3221	3204	x	0.79	-0.12		22.00
	6	4:35pm	4:20pm		22	101.6	4	2405	150.1	31.29		4537		x		-1.44	x	
	6					101.6	4	2429	151.6	28.15		4082		x		1.70	x	
	6					101.6	4	2429	151.6	29.75		4314		x		0.10		
	6					101.6	4	2381	148.6	30.21	29.85	4381	4329	x	1.30	-0.36		29.98
	7	5:35pm	5:18pm		22	101.6	4	2405	150.1	36.80		5336		x		0.67		
	7					101.6	4	2405	150.1	38.81		5627		x		-1.34		
	7					101.6	4	2432	151.8	35.36		5127		x		2.11	x	
	7					101.6	4	2429	151.6	38.90	37.47	5640	5433	x	1.71	-1.43		38.17
5-12-A	12.25	11:00pm	5:45pm	6:30pm	24	101.6	4	2405	150.1	41.07		5955		x		-1.31		
5-12-B	12.25					101.6	4	2405	150.1	40.17		5825		x		-0.41		
5-12-C	12.25					101.6	4	2381	148.6	36.37		5274		c		3.39	x	
5-12-D	12.25					101.6	4	2405	150.1	41.42	39.76	6006	5765	x	2.32	-1.66		40.89
5-24-A	25	11:45am			23	101.6	4	2429	151.6	48.12		6978		x		-6.08	x	
5-24-B	25					101.6	4	2357	147.1	41.68		6044		x		0.37		
5-24-C	25					101.6	4	2357	147.1	37.86		5489		x		4.19		
5-24-D	25					101.6	4	2381	148.6	40.53	42.05	5877	6097	x	4.36	1.52		40.02
5-3-A	74	12:45pm		10:10pm		98.4	3-7/8	2432	151.8	52.74		7648		x		-3.03	x	
5-3-B	74					98.4	3-7/8	2406	150.2	48.75		7069		x		0.97		
5-3-C	74					104.8	4-1/8	2379	148.5	47.66	49.72	6910	7209	x	2.68	2.06		48.20
5-7-A	172	2:45pm				98.4	3-7/8	2382	148.7	49.28		7146		c		3.76	x	
5-7-B	172					98.4	3-7/8	2406	150.2	54.52		7906		x		-1.48		
5-7-C	172					98.4	3-7/8	2432	151.8	55.33	53.05	8023	7692	x	3.28	-2.29		54.93
5-28-A	678	4:45pm			23	104.8	4-1/8	2355	147	61.44		8909		x		0.72		
5-28-B						104.8	4-1/8	2379	148.5	60.70		8802		x		1.45		
5-28-C						104.8	4-1/8	2403	150	62.17		9014		x		-0.01		
5-28-D						104.8	4-1/8	2379	148.5	64.32	62.16	9326	9013	x	1.56	-2.16	x	61.44
5-28S-A	678	5:00pm	12:10pm	3:30pm	23	101.6	4	2405	150.1	64.17		9304		x		2.73		
5-28S-B						101.6	4	2429	151.6	71.11		10311		x		-4.22	x	
5-28S-C						101.6	4	2429	151.6	67.21		9745		x		-0.31		
5-28S-D						101.6	4	2405	150.1	65.10	66.89	9439	9700	x	3.08	1.80		65.49

x=conical break c=corner break s= vertical split break

Temperature Log Data and Calculated Maturity						Limiting, Su	Mix	A
			10 min =	0.16667	hours	63.79	Trial	4
Date	Time	Temp, T (C)	Age, t (min)	Age, t (hr)	Maturity, M (C-hrs)	Strength, S (MPa)	Relative, S/Su	
					0 datum			
time mixed	10:49:00	23	0	0.00	0			
	10:59:00	23	10	0.17	4			
	11:09:00	23	20	0.33	8			
	11:19:00	23	30	0.50	12			
	11:29:00	23	40	0.67	15			
	11:39:00	23	50	0.83	19			
	11:49:00	23	60	1.00	23			
3/5/2002	11:59:38	23	70	1.17	27			
3/5/2002	12:09:38	23	80	1.33	31			
3/5/2002	12:19:38	23	90	1.50	35			
3/5/2002	12:29:38	24	100	1.67	39			
3/5/2002	12:39:38	24	110	1.83	43			
3/5/2002	12:49:38	26	120	2.00	47			
3/5/2002	12:59:38	27	130	2.17	51			
3/5/2002	13:09:38	30	140	2.33	56			
3/5/2002	13:19:38	32	150	2.50	62			
3/5/2002	13:29:38	34	160	2.67	67			
3/5/2002	13:39:38	35	170	2.83	73			
3/5/2002	13:49:38	37	180	3.00	79			
3/5/2002	13:59:38	38	190	3.17	86			
3/5/2002	14:09:38	41	200	3.33	93			
3/5/2002	14:19:38	41	210	3.50	99			
3/5/2002	14:29:38	42	220	3.67	106			
3/5/2002	14:39:38	44	230	3.83	114			
3/5/2002	14:49:38	45	240	4.00	121			
3/5/2002	14:59:38	47	250	4.17	129			
3/5/2002	15:09:38	49	260	4.33	137			
3/5/2002	15:19:38	51	270	4.50	146			
3/5/2002	15:29:38	55	280	4.67	155			
3/5/2002	15:39:38	57	290	4.83	164			
3/5/2002	15:49:38	59	300	**5.00**	**174**	**22.00**	**0.345**	
3/5/2002	15:59:38	60	310	5.17	184			
3/5/2002	16:09:38	60	320	5.33	194			
3/5/2002	16:19:38	60	330	5.50	204			
3/5/2002	16:29:38	59	340	5.67	214			
3/5/2002	16:39:38	58	350	**5.83**	**224**	**29.98**	**0.470**	
3/5/2002	16:49:38	57	360	6.00	233			
3/5/2002	16:59:38	56	370	6.17	243			
3/5/2002	17:09:38	55	380	6.33	252			
3/5/2002	17:19:38	55	390	6.50	261			
3/5/2002	17:29:38	55	400	6.67	270			
3/5/2002	17:39:38	55	410	**6.83**	**279**	**38.17**	**0.598**	
untarped	17:49:38	55	420	7.00	288			
3/5/2002	17:59:38	54	430	7.17	297			
3/5/2002	18:09:38	23	440	**12.25**	**414**	**40.89**	**0.641**	
3/5/2002	18:19:38	23	450	**25.00**	**708**	**40.02**	**0.627**	
		23	460	**74.00**	**1835**	**48.20**	**0.756**	
		23	470	**172.00**	**4089**	**54.93**	**0.861**	
		23	480	**678.00**	**15727**	**61.44**	**0.963**	

Strength Age Data

Mix B
Trial 1

Test #: 10 Date: March 8/02 Bed #: 3

Time Batched: 10:41am (D10:41:59) (22)
Time Extruded: 10:52am
Time Samples cut: 12:00pm

Time 28-day in tank: 3:30pm
Time Bed Tarped: 12:02pm

Time Bed Untarped: 5:10pm
Concrete Temp.: 21°C @ 10:54am@11:52am

Ambient Temp.: 22°C@10:52am
Consistency: Normal

Mix Design: HC-1 1200-30 ____ -10 ____ -FA
Actual Quantities: (batch = 2 cuy)

							In bed
Type 30	1196	lbs/2yd³	355	kg/m³	Hobo #	1A	
Type 10	5	lbs/2yd³	1	kg/m³	Time laun.	11:02am	12:05pm
FA	0	lbs/2yd³	0	kg/m³	Hobo #	1B	
Sand	4410	lbs/2yd³	1308	kg/m³	Time laun.	11:02am	12:05pm
Stone	3585	lbs/2yd³	1058	kg/m³			
730 fcs	48	oz/2yd³	421	mL/m³			

cylinder break: 4038 @ 7.5 hrs
4397 @ 7.5hrs

Sample ID	Test Age	Time	Time Extracted	Time In Tank	Tank Temp.	Core Size (L)	Core Size (L)	Density	Density	Strength	Average	Strength	Average	Type of break	StDev	Difference Ave. - Stren.	Not Included in Average	New Average
	(hr)	(at break)	(from bed)		(°C)	(mm)	(inches)	(kg/m³)	(pcf)	(Mpa)	(Mpa)	(psi)	(psi)		(Mpa)	(Mpa)		(Mpa)
	4.5	3:14pm	2:57pm		23	101.6	4	2429	151.6	20.29		2942		x		0.79		
						101.6	4	2429	151.6	21.20		3074		x		-0.12		
						101.6	4	2429	151.6	22.68		3288		x		-1.60	x	
						101.6	4	2429	151.6	20.15	21.08	2922	3057	x	1.16	0.93		20.55
	5	3:50pm	3:40pm		22	101.6	4	2357	147.1	27.36		3967		x		0.91	x	
						101.6	4	2381	148.6	28.30		4103		x		-0.02		
						101.6	4	2381	148.6	28.77		4171		x		-0.49		
						101.6	4	2405	150.1	28.67	28.27	4157	4100	x	0.64	-0.40		28.58
	6.5	5:00pm	4:42pm		22	101.6	4	2405	150.1	30.10		4364		x		3.19	x	
						101.6	4	2429	151.6	35.69		5175		x		-2.40		
						101.6	4	2405	150.1	32.85		4763		x		0.44		
						101.6	4	2405	150.1	34.53	33.29	5007	4827	x	2.43	-1.24		34.36
10-12-A	12	10:40pm	5:30pm	6:30pm		101.6	4	2381	148.6	38.26		5548		x		1.73		
10-12-B						101.6	4	2381	148.6	38.27		5549		x		1.73		
10-12-C						101.6	4	2429	151.6	42.97		6230		x		-2.97	x	
10-12-D						101.6	4	2405	150.1	40.49	40.00	5871	5800	x	2.24	-0.49		39.01
10-24-A	21	7:30pm		7:30pm	22	101.6	4	2381	148.6	42.87		6216		x		1.49		
10-24-B						101.6	4	2429	151.6	46.73		6776		x		-2.37		
10-24-C						101.6	4	2381	148.6	40.39		5856		x		3.97	x	
10-24-D						101.6	4	2429	151.6	47.45	44.36	6880	6432	x	3.33	-3.09		45.68
10-3-A	79	5:39pm			23	101.6	4	2381	148.6	46.76		6780		x		1.22		
10-3-B						101.6	4	2429	151.6	49.03		7109		split		-1.05		
10-3-C						101.6	4	2453	153.1	52.01		7542		x		-4.04	x	
10-3-D						101.6	4	2331	145.5	44.10	47.97	6394	6956	x	3.36	3.88	x	47.89
10-7-A	170	12:10pm			23	101.6	4	2357	147.1	47.92		6948		x		0.51		
10-7-B						101.6	4	2405	150.1	53.77		7797		x		-5.35		
10-7-C						101.6	4	2357	147.1	54.58		7914		x		-6.15		
10-7-D						101.6	4	2429	151.6	37.43	48.43	5428	7022	x	7.91	10.99	x	52.09
10-28-A	678	5:02pm	7:20pm		24	101.6	4	2429	151.6	64.76		9390		x		-0.26		
10-28-B						101.6	4	2405	150.1	69.88		10133		x		-5.38	x	
10-28-C						101.6	4	2357	147.1	57.99		8408		x		6.51	x	
10-28-D						101.6	4	2357	147.1	65.37	64.60	9479	9353	c	4.91	-0.87		65.07
10-28S-A	678	5:10pm	12:00pm	3:30pm	23	101.6	4	2405	150.1	66.10		9584		x		1.06		
10-28S-B						101.6	4	2405	150.1	67.47		9783		x		-0.31		
10-28S-C						101.6	4	2381	148.6	66.41		9630		x		0.74		
10-28S-D						101.6	4	2405	150.1	68.64	67.16	9953	9738	x	1.15	-1.49	x	66.66

x=conical break c=corner break s= vertical split break

Temperature Log Data and Calculated Maturity						Limiting, Su	Mix	B
			10 min =	0.16667	hours	65.72	Trial	1
Date	Time	Temp, T (C)	Age, t (min)	Age, t (hr)	Maturity, M (C-hrs)	Strength, S (MPa)	Relative, S/Su	
					0 datum			
time mixed	10:42	19	0	0.00	0			
	10:52	19	10	0.17	3			
3/8/2002	11:02:37	19	20	0.33	6			
3/8/2002	11:12:37	19	30	0.50	10			
3/8/2002	11:22:37	19	40	0.67	13			
3/8/2002	11:32:37	19	50	0.83	16			
3/8/2002	11:42:37	19	60	1.00	19			
3/8/2002	11:52:37	18	70	1.17	22			
3/8/2002	12:02:37	25	80	1.33	26			
3/8/2002	12:12:37	26	90	1.50	31			
3/8/2002	12:22:37	27	100	1.67	35			
3/8/2002	12:32:37	29	110	1.83	40			
3/8/2002	12:42:37	31	120	2.00	45			
3/8/2002	12:52:37	32	130	2.17	50			
3/8/2002	13:02:37	34	140	2.33	56			
3/8/2002	13:12:37	36	150	2.50	62			
3/8/2002	13:22:37	38	160	2.67	68			
3/8/2002	13:32:37	40	170	2.83	75			
3/8/2002	13:42:37	41	180	3.00	82			
3/8/2002	13:52:37	43	190	3.17	89			
3/8/2002	14:02:37	45	200	3.33	97			
3/8/2002	14:12:37	47	210	3.50	104			
3/8/2002	14:22:37	49	220	3.67	113			
3/8/2002	14:32:37	52	230	3.83	121			
3/8/2002	14:42:37	53	240	4.00	130			
3/8/2002	14:52:37	55	250	4.17	139			
3/8/2002	15:02:37	55	260	4.33	148			
3/8/2002	15:12:37	55	270	**4.50**	**158**	**20.55**	**0.313**	
3/8/2002	15:22:37	56	280	4.67	167			
3/8/2002	15:32:37	56	290	4.83	176			
3/8/2002	15:42:37	56	300	5.00	186			
3/8/2002	15:52:37	55	310	**5.17**	**195**	**28.58**	**0.435**	
3/8/2002	16:02:37	54	320	5.33	204			
3/8/2002	16:12:37	54	330	5.50	213			
3/8/2002	16:22:37	54	340	5.67	222			
3/8/2002	16:32:37	54	350	5.83	231			
3/8/2002	16:42:37	53	360	6.00	240			
3/8/2002	16:52:37	53	370	6.17	248			
3/8/2002	17:02:37	53	380	**6.33**	**257**	**34.36**	**0.523**	
3/8/2002	17:12:37	52	390	6.50	266			
untarped	17:22:37	51	400	6.67	274			
3/8/2002		23	410	**12.00**	**397**	**39.01**	**0.594**	
		23	420	**21.00**	**604**	**45.68**	**0.695**	
		23	430	**79.00**	**1938**	**47.89**	**0.729**	
		23	440	**170.00**	**4031**	**52.09**	**0.793**	
		23	450	**678.00**	**15715**	**65.07**	**0.990**	

Strength Age Data

Mix B
Trial 2

Test #: 11 Date: March 14/02 Bed #: 3

Time Batched: D11:48:27 (1)
Time Extruded: 12:20pm
Time Samples cut: 12:30pm

Time 28-day in tank: 5:37pm
Time Bed Tarped: 1:45pm

Time Bed Untarped: 8:00pm
Concrete Temp.: 19°C @ 12:23pm

Ambient Temp.: 17°C@12:23pm
Consistency: Dry (whisper)

Mix Design: HC-1 1200-30 -10 -FA
Actual Quantities: (batch = 2 cuy)

								in bed
Type 30	1190	lbs/2yd^3	353	kg/m^3	Hobo #	1A		
Type 10	14	lbs/2yd^3	4	kg/m^3	Time laun.	12:28pm	12:30pm	
FA	0	lbs/2yd^3	0	kg/m^3	Hobo #	1B		
Sand	4375	lbs/2yd^3	1298	kg/m^3	Time laun.	12:29pm	12:30pm	
Stone	3595	lbs/2yd^3	1066	kg/m^3				
730 fcs	48	oz/2yd^3	421	mL/m^3	cylinder break: 3561 @ 6 hrs			

Sample ID	Test Age	Time	Time Extracted	Time in Tank	Tank Temp.	Core Size (L)	Core Size (L)	Density	Density	Strength	Average	Strength	Average	Type of break	StDev	Difference Ave. - Stren.	Included in Average	New Average
	(hr)	(at break)	(from bed)		(°C)	(mm)	(inches)	(kg/m^3)	(pcf)	(Mpa)	(Mpa)	(psi)	(psi)		(Mpa)	(Mpa)		(Mpa)
	4.5	4:30pm	4:20pm		23	101.6	4	2429	151.6	13		1885		x				
						101.6	4	2413	150.6	13.92	13.46	2019	1952	x				13.46
	5.5	5:30pm	5:17pm		24	101.6	4	2405	150.1	16.69		2420		x		3.56		
						101.6	4	2381	148.6	16.02		2323		x		4.23		
						101.6	4	2405	150.1	25.55		3705		x		-5.30	x	
						101.6	4	2405	150.1	22.73	20.25	3296	2936	x	4.65	-2.48		18.48
	6.5	6:30pm	6:10pm		23	101.6	4	2429	151.6	38.21		5540		x		-1.47	x	
						101.6	4	2429	151.6	36.41		5280		x		0.32		
						101.6	4	2429	151.6	35.97		5215		x		0.77		
						101.6	4	2405	150.1	36.35	36.73	5271	5327	x	1.00	0.38		36.24
	9.5	9:30pm	8:15pm	10:30pm		101.6	4	2453	153.1	42.85		6213		c		-0.53		
						101.6	4	2453	153.1	42.05		6097		x		0.27		
						101.6	4	2453	153.1	43.34		6285		x		-1.03	x	
						101.6	4	2453	153.1	41.01	42.31	5947	6136	x	1.02	1.30	x	42.45
11-24-A	24	12:00pm			23	101.6	4	2381	148.6	41.28		5985		x		0.33		
11-24-B						101.6	4	2429	151.6	44.28		6420		x		-2.67	x	
11-24-C						101.6	4	2405	150.1	38.08		5521		x		3.53	x	
11-24-D						101.6	4	2429	151.6	42.78	41.60	6203	6203	x	2.65	-1.18		42.03
11-3-A	95	10:30pm				101.6	4	2429	151.6	61.97		8985		x		-6.43	x	
11-3-B		18-Mar				101.6	4	2405	150.1	56.56		8201		x		-1.02		
11-3-C						101.6	4	2429	151.6	54.12		7847		x		1.42		
11-3-D						101.6	4	2405	150.1	49.51	55.54	7179	8053	x	5.19	6.03	x	55.34
11-7-A	171	3:15pm			22	101.6	4	2429	151.6	58.32		8457		x		-2.10	x	
11-7-B						101.6	4	2453	153.1	54.39		7887		x		1.83	x	
11-7-C						101.6	4	2453	153.1	57.14		8285		x		-0.91		
11-7-D						101.6	4	2405	150.1	55.06	56.23	7983	8153	c	1.82	1.17		56.10
11-28-A	676	3:45pm			22	101.6	4	2453	153.1	66.10		9585		x		-7.92	x	
11-28-B						101.6	4	2405	150.1	61.86		8969		x		-3.67		
11-28-C						101.6	4	2429	151.6	57.28		8306		x		0.90		
11-28-D						101.6	4	2429	151.6	56.08		8131		x		2.11		
11-28-E						101.6	4	2405	150.1	57.04		8271		x		1.14		
11-28-F						101.6	4	2429	151.6	50.76	58.19	7360	8652	c	5.25	7.43	x	58.06
11-28S-A	676	4:00pm	12:30pm	5:37pm	23	101.6	4	2429	151.6	68.37		9913		x		-3.64		
11-28S-B						101.6	4	2405	150.1	59.68		8653		x		5.05	x	
11-28S-C						101.6	4	2405	150.1	66.58		9654		x		-1.85		
11-28S-D						95.3	3-3/4	2358	147.2	64.28	64.73	9321	9629	x	3.76	0.44		66.41

x=conical break c=corner break s= vertical split break

Temperature Log Data and Calculated Maturity						Limiting, Su	Mix	B	
			10 min =	0.16667	hours	64.99	Trial	2	
Date	Time	Temp, T (C)	Age, t (min)	Age, t (hr)	Maturity, M (C-hrs)	Strength, S (MPa)	Relative, S/Su		
					0 datum				
time mixed	11:47	19	0	0.00	0				
	11:57	19	10	0.17	3				
	12:07:00	19	20	0.33	6				
	12:17	19	30	0.50	10				
3/14/2002	12:27:59	20	40	0.67	13				
3/14/2002	12:37:59	10	50	0.83	15				
3/14/2002	12:47:59	17	60	1.00	17				
3/14/2002	12:57:59	15	70	1.17	20				
3/14/2002	13:07:59	14	80	1.33	22				
3/14/2002	13:17:59	14	90	1.50	25				
3/14/2002	13:27:59	14	100	1.67	27				
3/14/2002	13:37:59	15	110	1.83	29				
3/14/2002	13:47:59	17	120	2.00	32				
3/14/2002	13:57:59	19	130	2.17	35				
3/14/2002	14:07:59	21	140	2.33	39				
3/14/2002	14:17:59	23	150	2.50	43				
3/14/2002	14:27:59	24	160	2.67	47				
3/14/2002	14:37:59	27	170	2.83	51				
3/14/2002	14:47:59	29	180	3.00	56				
3/14/2002	14:57:59	30	190	3.17	61				
3/14/2002	15:07:59	31	200	3.33	66				
3/14/2002	15:17:59	34	210	3.50	72				
3/14/2002	15:27:59	35	220	3.67	78				
3/14/2002	15:37:59	37	230	3.83	84				
3/14/2002	15:47:59	38	240	4.00	90				
3/14/2002	15:57:59	40	250	4.17	97				
3/14/2002	16:07:59	41	260	4.33	104				
3/14/2002	16:17:59	43	270	4.50	111				
3/14/2002	16:27:59	43	280	4.67	118	13.46	0.207		
3/14/2002	16:37:59	45	290	4.83	126				
3/14/2002	16:47:59	46	300	5.00	133				
3/14/2002	16:57:59	47	310	5.17	141				
3/14/2002	17:07:59	48	320	5.33	149				
3/14/2002	17:17:59	49	330	5.50	157				
3/14/2002	17:27:59	49	340	5.67	165	18.48	0.284		
3/14/2002	17:37:59	49	350	5.83	174				
3/14/2002	17:47:59	49	360	6.00	182				
3/14/2002	17:57:59	49	370	6.17	190				
3/14/2002	18:07:59	50	380	6.33	198				
3/14/2002	18:17:59	49	390	6.50	206				
3/14/2002	18:27:59	49	400	6.67	215	36.24	0.558		
3/14/2002	18:37:59	49	410	6.83	223				
3/14/2002	18:47:59	48	420	7.00	231				
3/14/2002	18:57:59	48	430	7.17	239				
3/14/2002	19:07:59	46	440	7.33	246				
3/14/2002	19:17:59	42	450	7.50	253				
3/14/2002	19:27:59	40	460	7.67	260				
3/14/2002	19:37:59	38	470	7.83	266				
untarped	19:47:59	36	480	8.00	272				
3/14/2002	19:57:59	23	490	9.50	307	42.45	0.653		
		23	500	24.00	640	42.03	0.647		
		23	510	95.00	2273	55.34	0.851		
		23	520	171.00	4021	56.10	0.863		
		23	530	676.00	15636	58.06	0.893		

Strength Age Data

Mix B
Trial 3

Test #: 12 Date: March 15/02 Bed #: 2

Time Batched: D10:21:14 (21)
Time Extruded: 10:30am
Time Samples cut: 11:45am

Time 28-day in tank: 5:45pm
Time Bed Tarped: 11:50am

Time Bed Untarped: 5:50pm
Concrete Temp.: 20°C @ 11:30am

Ambient Temp.: 24°C@11:30am
Consistency: Normal

Mix Design: HC-1 1200-30 ____ -10 ____ -FA
Actual Quantities: (batch = 2 cuy)

							in bed
Type 30	1228	lbs/2yd³	364	kg/m³	Hobo #	1A	
Type 10	0	lbs/2yd³	0	kg/m³	Time laun.	11:30am	11:50am
FA	0	lbs/2yd³	0	kg/m³	Hobo #	1B	
Sand	4390	lbs/2yd³	1302	kg/m³	Time laun.	11:30am	11:50am
Stone	3610	lbs/2yd³	1071	kg/m³			
730 fcs	48	oz/2yd³	421	mL/m³			

cylinder break: 3666 @ 7 hrs

Sample ID	Test Age	Time	Time Extracted	Time In Tank	Tank Temp.	Core Size (L)	Core Size (L)	Density	Density	Strength	Average	Strength	Average	Type of break	StDev	Difference Ave. - Stren.	Not Included in Average	New Average
	(hr)	(at break)	(from bed)		(°C)	(mm)	(inches)	(kg/m³)	(pcf)	(Mpa)	(Mpa)	(psi)	(psi)		(Mpa)	(Mpa)		(Mpa)
	5	3:30pm	3:14pm		23	101.6	4	2381	148.6	11.19		1623		c		0.59	x	
						101.6	4	2381	148.6	11.71		1698		x		0.08		
						101.6	4	2405	150.1	11.70		1696		x		0.09		
						101.6	4	2405	150.1	12.54	11.79	1819	1709	x	0.56	-0.76	x	11.70
	6	4:30pm	4:18pm		23	101.6	4	2429	151.6	25.50		3698		x		0.24		
						101.6	4	2381	148.6	23.38		3390		x		2.36	x	
						101.6	4	2429	151.6	26.87		3896		x		-1.13		
						101.6	4	2405	150.1	27.21	25.74	3945	3732	x	1.74	-1.47		26.53
	7	5:30pm	5:18pm		23	101.6	4	2429	151.6	30.55		4430		x		-1.33		
						101.6	4	2429	151.6	30.90		4481		x		-1.68		
						101.6	4	2381	148.6	28.81		4177		x		0.41		
						101.6	4	2381	148.6	26.61	29.22	3859	4237	x	1.96	2.61	x	30.09
12-12-A	12.5	10:50pm	5:55pm	7:05pm	23	101.6	4	2429	151.6	37.25		5401		x		-1.52	x	
12-12-B						101.6	4	2405	150.1	35.68		5174		x		0.04		
12-12-C						101.6	4	2405	150.1	34.09		4943		x		1.64	x	
12-12-D						92.1	3-5/8	2385	148.9	35.89	35.73	5204	5181	x	1.29	-0.16		35.79
12-24-A	24	10:30am			23	101.6	4	2429	151.6	39.88		5782		x		-1.17		
12-24-B						101.6	4	2405	150.1	35.58		5159		x		3.13	x	
12-24-C						101.6	4	2381	148.6	38.60		5597		x		0.11		
12-24-D						101.6	4	2405	150.1	40.79	38.71	5914	5613	x	2.27	-2.08		39.75
12-3-A	72	10:20am			27	101.6	4	2429	151.6	48.83		7080		x		-2.09	x	
12-3-B						101.6	4	2405	150.1	47.61		6904		x		-0.88		
12-3-C						101.6	4	2429	151.6	45.30		6568		c		1.44		
12-3-D						101.6	4	2405	150.1	45.21	46.74	6555	6777	x	1.78	1.53		46.04
12-7-A	177	7:40pm			23	104.8	4-1/8	2403	150	56.11		8136		x		0.22		
12-7-B						104.8	4-1/8	2403	150	54.06		7839		x		2.26	x	
12-7-C						104.8	4-1/8	2425	151.4	57.51		8339		x		-1.18		
12-7-D						104.8	4-1/8	2403	150	57.62	56.33	8355	8167	x	1.66	-1.29		57.08
12-28-A	694	8:30am Apr 13			21	101.6	4	2429	151.6	64.54		9359		x		-5.18		
12-28-B						101.6	4	2381	148.6	52.13		7559		s		7.23	x	
12-28-C						101.6	4	2429	151.6	62.50		9063		x		-3.14		
12-28-D						101.6	4	2429	151.6	58.28	59.37	8451	8608	c	5.48	1.08		61.78
12-28S-A	694	8:45am Apr 13	11:45am	5:45pm	21	101.6	4	2429	151.6	53.50		7758		x		3.63	x	
12-28S-B						101.6	4	2405	150.1	57.23		8298		x		-0.09		
12-28S-C						101.6	4	2429	151.6	59.09		8568		x		-1.96		
12-28S-D						101.6	4	2405	150.1	58.72	57.13	8514	8285	x	2.55	-1.58		58.34

-On Mar 18/02 the tank temperature rose to 56C for 31 hrs
-Ssss tests must have been affected by the high temperature at 3 days age

x=conical break c=corner break s= vertical split break

Temperature Log Data and Calculated Maturity						Limiting, Su	Mix	B
			10 min =	0.16667	hours	67.74	Trial	3
Date	Time	Temp, T (C)	Age, t (min)	Age, t (hr)	Maturity, M (C-hrs)	Strength, S (MPa)	Relative, S/Su	
					0 datum			
time mixed	10:26	20	0	0.00	0			
	10:36	20	10	0.17	3			
	10:46	20	20	0.33	7			
	10:56	20	30	0.50	10			
	11:06	20	40	0.67	13			
	11:16	20	50	0.83	17			
	11:26	20	60	1.00	20			
3/15/2002	11:36:49	22	70	1.17	24			
3/15/2002	11:46:49	23	80	1.33	28			
3/15/2002	11:56:49	23	90	1.50	31			
3/15/2002	12:06:49	24	100	1.67	35			
3/15/2002	12:16:49	26	110	1.83	40			
3/15/2002	12:26:49	27	120	2.00	44			
3/15/2002	12:36:49	29	130	2.17	49			
3/15/2002	12:46:49	30	140	2.33	54			
3/15/2002	12:56:49	32	150	2.50	59			
3/15/2002	13:06:49	33	160	2.67	65			
3/15/2002	13:16:49	34	170	2.83	71			
3/15/2002	13:26:49	35	180	3.00	76			
3/15/2002	13:36:49	37	190	3.17	83			
3/15/2002	13:46:49	39	200	3.33	89			
3/15/2002	13:56:49	41	210	3.50	96			
3/15/2002	14:06:49	42	220	3.67	103			
3/15/2002	14:16:49	44	230	3.83	110			
3/15/2002	14:26:49	45	240	4.00	118			
3/15/2002	14:36:49	46	250	4.17	125			
3/15/2002	14:46:49	48	260	4.33	133			
3/15/2002	14:56:49	49	270	4.50	142			
3/15/2002	15:06:49	51	280	4.67	150			
3/15/2002	15:16:49	52	290	4.83	159			
3/15/2002	15:26:49	52	300	**5.00**	**167**	**11.70**	**0.173**	
3/15/2002	15:36:49	53	310	5.17	176			
3/15/2002	15:46:49	54	320	5.33	185			
3/15/2002	15:56:49	54	330	5.50	194			
3/15/2002	16:06:49	54	340	5.67	203			
3/15/2002	16:16:49	55	350	5.83	212			
3/15/2002	16:26:49	55	360	**6.00**	**222**	**26.53**	**0.392**	
3/15/2002	16:36:49	56	370	6.17	231			
3/15/2002	16:46:49	56	380	6.33	240			
3/15/2002	16:56:49	56	390	6.50	250			
3/15/2002	17:06:49	56	400	6.67	259			
3/15/2002	17:16:49	56	410	6.83	268			
3/15/2002	17:26:49	57	420	**7.00**	**278**	**30.09**	**0.444**	
3/15/2002	17:36:49	58	430	7.17	287			
untarped	17:46:49	57	440	7.33	297			
3/15/2002		23	450	**12.50**	**416**	**35.79**	**0.528**	
		23	460	**24.00**	**680**	**39.75**	**0.587**	
		23	470	**72.00**	**1784**	**46.04**	**0.680**	
		23	480	**177.00**	**4199**	**57.08**	**0.843**	
		23	490	**694.00**	**16090**	**61.78**	**0.912**	

Strength Age Data

Mix C
Trial 1

Test #: ___ 1 Date: ____ Feb 13/02 Bed #: __ 2

Time Batched: _______ 4:13 pm D16:06:16 (24) Mix Design: HC-1 300-30 __900 -10 _____-FA
Time Extruded: _______ 4:18pm
Time Samples cut: ____ 5:15pm

Time 28-day in tank: __ 6:00pm
Time Bed Tarped: ____ 5:30pm

Time Bed Untarped: 4:10am
Concrete Temp.:______ 13°C at ext.
11C at 5:20pm
Ambient Temp.:______ 14°C
Consistency: ________ Normal

Actual Quantities: (batch = 2 cuy)

							in bed
Type 30	302	lbs/2yd^3	90	kg/m^3	Hobo #	1A	5:20pm
Type 10	868	lbs/2yd^3	257	kg/m^3	Time laun.	4:28pm	
FA	32	lbs/2yd^3	9	kg/m^3	Hobo #	1B	5:20pm
Sand	4400	lbs/2yd^3	1305	kg/m^3	Time laun.	4:29pm	
Stone	3555	lbs/2yd^3	1055	kg/m^3			
730 fcs	48	oz/2yd^3	421	mL/m^3			

cylinder break:_3979 at 11.5hrs

Sample ID	Approx. Test Age	Acutal Age	Time Extracted	Time In Tank	Tank Temp.	Core Size (L)	Core Size (L)	Density	Density	Strength	Average	Strength	Average	Type of break	StDev	Difference Ave. - Stren.	Not Included in Average	New Average
		(at break)	(from bed)		(°C)	(mm)	(inches)	(kg/m^3)	(pcf)	(Mpa)	(Mpa)	(psi)	(psi)		(Mpa)	(Mpa)		(Mpa)
	4 hr	5.5	9:00pm			50.8	2					no load						
	4 hr																	
	4 hr																	
	8 hr	7.5	11:30pm			101.6	4	2477	154.6	16.37		2374		s				
	8 hr	7.5	11:30pm			101.6	4	2381	148.6	12.66	14.52	1836	2105	c				14.52
	8 hr																	
	12 hr	13	4:40am		22	101.6	4	2461	153.6	33.81		4903		x				
	12 hr	13	4:40am		22	101.6	4	2405	150.1	32.44	33.13	4704	4804	x				33.13
	12 hr																	
	16 hr	17.5	5:00pm	5:02pm	23	101.6	4	2453	153.1	35.41		5135		c				
	16 hr	17.5	5:00pm	5:02pm	23	98.4	3-7/8	2481	154.9	37.21	36.31	5396	5266	x				36.31
	16 hr																	
	20 hr	24	5:00pm	5:02pm	23	98.4	3-7/8	2406	150.2	38.77		5621		x				
	20 hr	24	5:00pm	5:02pm	23	98.4	3-7/8	2406	150.2	37.86	38.31	5490	5556	x				38.31
	20 hr																	
1-3-A	3 day	72				101.6	4	2405	150.1	40.77		5912		x				
1-3-B	3 day	72				95.3	3-3/4	2403	150.0	41.66	41.22	6041	5977	x				41.22
	3 day																	
1-7-A	7 day	168				98.4	3-7/8	2507	156.5	52.19		7567		x				
1-7-B	7 day	168				98.4	3-7/8	2432	151.8	50.92	51.55	7383	7475	x				51.55
	7 day																	
1-28-A	28 day	673				98.4	3-7/8	2457	153.4	51.90		7526		x		2.19	x	
1-28-B	28day	673				95.3	3-3/4	2451	153.0	56.92		8253		x		-2.83	x	
	28day	673				95.3	3-3/4	2409	150.4	53.26		7723		x		0.83		
	28day	673				101.6	4	2405	150.1	54.28	54.09	7871	7843	x	2.12	-0.19		53.77
1-28S-A	28day std	673	6:00pm	6:00pm		82.6	3-1/4		396g	55.17		8000		x		1.40		
1-28s-B	28day std	673				93.3	3-5/8	2385	148.9	56.26		8158		x		0.31		
	28day std							2409	150.4	58.28	56.57	8451	8203	c	1.58	-1.71	x	55.72

x=conical break c=corner break s= vertical split break

Temperature Log Data and Calculated Maturity						Limiting, Su	Mix	C
			10 min =	0.1666667	hours	58.67	Trial	1
Date	Time	Temp, T (C)	Age, t (min)	Age, t (hr)	Maturity, M (C-hrs)	Strength, S (MPa)	Relative, S/Su	
time mixed	16:13	15			0 datum			
	16:18	15	0	0.00	0			
	16:28	15	10	0.17	3			
	16:38	15	20	0.33	5			
	16:48	15	30	0.50	8			
	17:08	15	40	0.67	10			
2/13/2002	17:18:17	15	50	0.83	13			
2/13/2002	17:28:17	15	60	1.00	15			
2/13/2002	17:38:17	15	70	1.17	18			
2/13/2002	17:48:17	15	80	1.33	20			
2/13/2002	17:58:17	16	90	1.50	23			
2/13/2002	18:08:17	17	100	1.67	25			
2/13/2002	18:18:17	18	110	1.83	28			
2/13/2002	18:28:17	19	120	2.00	31			
2/13/2002	18:38:17	19	130	2.17	34			
2/13/2002	18:48:17	20	140	2.33	37			
2/13/2002	18:58:17	21	150	2.50	41			
2/13/2002	19:08:17	22	160	2.67	44			
2/13/2002	19:18:17	23	170	2.83	48			
2/13/2002	19:28:17	24	180	3.00	52			
2/13/2002	19:38:17	24	190	3.17	56			
2/13/2002	19:48:17	26	200	3.33	60			
2/13/2002	19:58:17	27	210	3.50	64			
2/13/2002	20:08:17	28	220	3.67	69			
2/13/2002	20:18:17	29	230	3.83	73			
2/13/2002	20:28:17	30	240	4.00	78			
2/13/2002	20:38:17	31	250	4.17	83			
2/13/2002	20:48:17	31	260	4.33	88			
2/13/2002	20:58:17	32	270	4.50	93			
2/13/2002	21:08:17	32	280	4.67	99			
2/13/2002	21:18:17	32	290	4.83	104			
2/13/2002	21:28:17	34	300	5.00	109			
2/13/2002	21:38:17	34	310	5.17	115			
2/13/2002	21:48:17	34	320	5.33	121			
2/13/2002	21:58:17	35	330	5.50	126			
2/13/2002	22:08:17	36	340	5.67	132			
2/13/2002	22:18:17	38	350	5.83	138			
2/13/2002	22:28:17	39	360	6.00	145			
2/13/2002	22:38:17	39	370	6.17	151			
2/13/2002	22:48:17	40	380	6.33	158			
2/13/2002	22:58:17	41	390	6.50	164			
2/13/2002	23:08:17	41	400	6.67	171			
2/13/2002	23:18:17	41	410	6.83	178			
2/13/2002	23:28:17	41	420	7.00	185			
2/13/2002	23:38:17	41	430	7.17	192			
2/13/2002	23:48:17	41	440	7.33	198			
2/13/2002	23:58:17	40	450	**7.50**	**205**	**14.52**	**0.247**	
2/14/2002	0:08:17	40	460	7.67	212			
2/14/2002	0:18:17	40	470	7.83	219			
2/14/2002	0:28:17	40	480	8.00	225			
2/14/2002	0:38:17	40	490	8.17	232			
2/14/2002	0:48:17	40	500	8.33	239			
2/14/2002	0:58:17	40	510	8.50	245			
2/14/2002	1:08:17	40	520	8.67	252			
2/14/2002	1:18:17	40	530	8.83	259			
2/14/2002	1:28:17	40	540	9.00	265			
2/14/2002	1:38:17	41	550	9.17	272			
2/14/2002	1:48:17	41	560	9.33	279			
2/14/2002	1:58:17	41	570	9.50	286			
2/14/2002	2:08:17	41	580	9.67	292			
2/14/2002	2:18:17	41	590	9.83	299			
2/14/2002	2:28:17	41	600	10.00	306			
2/14/2002	2:38:17	41	610	10.17	313			
2/14/2002	2:48:17	41	620	10.33	320			
2/14/2002	2:58:17	41	630	10.50	327			

Temperature Log Data and Calculated Maturity						Limiting, Su	Mix	C
			10 min =	0.1666667	hours	58.67	Trial	1
Date	Time	Temp, T (C)	Age, t (min)	Age, t (hr)	Maturity, M (C-hrs)	Strength, S (MPa)	Relative, S/Su	
2/14/2002	3:08:17	41	640	10.67	333			
2/14/2002	3:18:17	41	650	10.83	340			
2/14/2002	3:28:17	40	660	11.00	347			
2/14/2002	3:38:17	40	670	11.17	354			
2/14/2002	3:48:17	40	680	11.33	360			
2/14/2002	3:58:17	40	690	11.50	367			
2/14/2002	4:08:17	40	700	11.67	374			
2/14/2002	4:18:17	38	710	11.83	380			
2/14/2002	4:28:17	37	720	12.00	387			
2/14/2002	4:38:17	11	730	12.17	393			
2/14/2002	4:48:17	12	740	12.33	395			
2/14/2002	4:58:17	32	750	12.50	397			
in tank	5:08:17	23	760	12.67	402			
2/14/2002	5:18:17	23	770	12.83	406			
2/14/2002		23	780	**13.00**	**410**	**33.13**	**0.565**	
		23	790	**17.50**	**513**	**36.31**	**0.619**	
		23		**24.00**	**663**	**38.31**	**0.653**	
		23		**72.00**	**1767**	**41.22**	**0.703**	
		23		**168.00**	**3975**	**51.55**	**0.879**	
				673.00	**15590**	**53.77**	**0.917**	

Strength Age Data

Mix **C**
Trial **2**

Test #: __ 2 Date: ___ Feb 14/02 Bed #: __ 3

Time Batched: _____ 2:55pm D14:53:37 (21 Mix Design: HC-1 300-30 __900 -10 _____-FA
Time Extruded: _____ 3:15pm
Time Samples cut: __ 3:45pm

Time 28-day in tank: 5:00pm
Time Bed Tarped: __ 4:30pm

Time Bed Untarped: 4:00am
Concrete Temp.:____ 13°C at 3:21 pm
15C @ 4:00pm
Ambient Temp.:____ 14°C
Consistency: ______ Normal

Actual Quantities: (batch = 2 cuy)

Type 30	267	$lbs/2yd^3$	79	kg/m^3
Type 10	892	$lbs/2yd^3$	265	kg/m^3
FA	66	$lbs/2yd^3$	20	kg/m^3
Sand	4380	$lbs/2yd^3$	1299	kg/m^3
Stone	3580	$lbs/2yd^3$	1062	kg/m^3
730 fcs	48	$oz/2yd^3$	421	mL/m^3

		in bed
Hobo #	1A	3:48pm
Time laun.	3:27pm	
Hobo #	1B	3:48pm
Time laun.	3:27pm	

cylinder break:_4637 at 14 hrs

Sample ID	Approx. Test Age	Time	Time Extracted	Time in Tank	Tank Temp.	Core Size (L)	Core Size (L)	Density	Density	Strength	Average	Strength	Average	Type of break	StDev	Difference Ave. - Stren.	Not Included in Average	New Average
		(at break)	(from bed)		(°C)	(mm)	(inches)	(kg/m^3)	(pcf)	(Mpa)	(Mpa)	(psi)	(psi)		(Mpa)	(Mpa)		(Mpa)
	4 hr																	
	4 hr																	
	4 hr																	
	8 hr (7.5)	10:26pm	10:20pm			101.6	4	2405	150.1	20.45		2965		x				
	8 hr (7.5)	10:26pm	10:20pm			93.3	3-5/8	2385	148.9	22.29	21.37	3232	3099	c				21.37
	12 hr (10.5	1:30am	1:14am			98.4	3-7/8	2382	148.7	22.19		3218		x				
	12 hr (10.5	1:30am	1:14am			101.6	4	2429	151.6	23.11	22.65	3351	3285	s				22.65
	16 hr (14)	5:00am	4:40am			101.6	4	2405	150.1	28.24		4095		x		1.56	x	
	16 hr (14)	5:00am	4:40am			88.9	3-1/2	2331	145.5	30.26		4387		x		-0.45		
	16 hr (14.5	5:20am	4:40am			101.6	4	2429	151.6	30.92	29.80	4483	4322	x	1.39	-1.11		30.59
	20 hr (19)	3:00pm		5:07am	23	101.6	4	2161	134.9	36.72		5325		x				
	20 hr (19)	3:00pm		5:07am	23	101.6	4	2161	134.9	37.02	36.87	5368	5347	x				36.87
2-4-A	4 day (96)		6:00am	7:52am	23	101.6	4	2331	145.5	36.80		5336		x		0.96	x	
2-4-B	4 day (96)					101.6	4	2381	148.6	38.45		5575		x		-0.69		
2-4-C	4 day (96)					101.6	4	2357	147.1	38.02	37.76	5513	5475	x	0.86	-0.26		38.23
2-7-A	7 day	168				101.6	4	2357	147.1	36.56		5301		x		1.33	x	
2-7-B	7 day					101.6	4	2357	147.1	38.88		5637		x		-0.99		
2-7-C	7 day					98.4	3-7/8	2382	148.7	38.23	37.89	5543	5494	x	1.20	-0.34		38.55
2-28-A	28 day	650				98.4	3-7/8	2357	147.1	45.02		6528		x		2.14	x	
2-28-B	28day					98.4	3-7/8	2331	145.5	48.05		6967		x		-0.88		
2-28-C	28day					98.4	3-7/8	2357	147.1	46.67		6767		x		0.49		
2-S-A	Spare					98.4	3-7/8	2382	148.7	48.92	47.16	7093	6839	x	1.70	-1.75	x	47.36
2-28S-A	28day std	650	5:00pm	5:00pm		98.4	3-7/8	2432	151.8	54.20		7859		x		-0.97		
2-28S-B	28day std		5:00pm	5:00pm		98.4	3-7/8	2432	151.8	49.28		7142		x		3.97	x	
2-28S-C	28day std					88.9	3-1/2	2448	152.8	56.23	53.23	8153	7718	x	3.59	-3.00		55.21

x=conical break c=corner break s= vertical split break

Temperature Log Data and Calculated Maturity						Limiting, Su	Mix	C
			10 min =	0.1666667	hours	49.96	Trial	2
Date	Time	Temp, T (C)	Age, t (min)	Age, t (hr)	Maturity, M (C-hrs)	Strength, S (MPa)	Relative, S/Su	
					0 datum			
time mixed	14:51	15	0	0.00	0			
	15:01	15	10	0.17	3			
	15:11	15	20	0.33	5			
	15:21	15	30	0.50	8			
2/14/2002	15:31:52	15	40	0.67	10			
2/14/2002	15:41:52	15	50	0.83	13			
2/14/2002	15:51:52	18	60	1.00	16			
2/14/2002	16:01:52	18	70	1.17	19			
2/14/2002	16:11:52	19	80	1.33	22			
2/14/2002	16:21:52	20	90	1.50	25			
2/14/2002	16:31:52	21	100	1.67	29			
2/14/2002	16:41:52	21	110	1.83	32			
2/14/2002	16:51:52	23	120	2.00	36			
2/14/2002	17:01:52	24	130	2.17	40			
2/14/2002	17:11:52	25	140	2.33	44			
2/14/2002	17:21:52	26	150	2.50	48			
2/14/2002	17:31:52	27	160	2.67	53			
2/14/2002	17:41:52	27	170	2.83	57			
2/14/2002	17:51:52	29	180	3.00	62			
2/14/2002	18:01:52	31	190	3.17	67			
2/14/2002	18:11:52	31	200	3.33	73			
2/14/2002	18:21:52	33	210	3.50	78			
2/14/2002	18:31:52	34	220	3.67	84			
2/14/2002	18:41:52	35	230	3.83	90			
2/14/2002	18:51:52	37	240	4.00	96			
2/14/2002	19:01:52	39	250	4.17	102			
2/14/2002	19:11:52	40	260	4.33	109			
2/14/2002	19:21:52	41	270	4.50	116			
2/14/2002	19:31:52	41	280	4.67	123			
2/14/2002	19:41:52	42	290	4.83	130			
2/14/2002	19:51:52	43	300	5.00	137			
2/14/2002	20:01:52	44	310	5.17	144			
2/14/2002	20:11:52	45	320	5.33	152			
2/14/2002	20:21:52	47	330	5.50	159			
2/14/2002	20:31:52	47	340	5.67	167			
2/14/2002	20:41:52	48	350	5.83	175			
2/14/2002	20:51:52	48	360	6.00	183			
2/14/2002	21:01:52	48	370	6.17	191			
2/14/2002	21:11:52	49	380	6.33	199			
2/14/2002	21:21:52	48	390	6.50	207			
2/14/2002	21:31:52	47	400	6.67	215			
2/14/2002	21:41:52	47	410	6.83	223			
2/14/2002	21:51:52	46	420	7.00	231			
2/14/2002	22:01:52	47	430	7.17	239			
2/14/2002	22:11:52	46	440	7.33	246			
2/14/2002	22:21:52	45	450	7.50	254			
2/14/2002	22:31:52	45	460	7.67	261	21.37	0.428	
2/14/2002	22:41:52	45	470	7.83	269			
2/14/2002	22:51:52	46	480	8.00	276			
2/14/2002	23:01:52	46	490	8.17	284			
2/14/2002	23:11:52	46	500	8.33	292			
2/14/2002	23:21:52	46	510	8.50	299			
2/14/2002	23:31:52	47	520	8.67	307			
2/14/2002	23:41:52	46	530	8.83	315			
2/14/2002	23:51:52	47	540	9.00	323			
2/15/2002	0:01:52	47	550	9.17	331			
2/15/2002	0:11:52	47	560	9.33	338			
2/15/2002	0:21:52	47	570	9.50	346			
2/15/2002	0:31:52	46	580	9.67	354			
2/15/2002	0:41:52	47	590	9.83	362			
2/15/2002	0:51:52	47	600	10.00	370			
2/15/2002	1:01:52	47	610	10.17	377			
2/15/2002	1:11:52	47	620	10.33	385			

Temperature Log Data and Calculated Maturity						Limiting, Su	Mix	C
			10 min =	0.1666667	hours	49.96	Trial	2
Date	Time	Temp, T (C)	Age, t (min)	Age, t (hr)	Maturity, M (C-hrs)	Strength, S (MPa)	Relative, S/Su	
2/15/2002	1:21:52	47	630	10.50	393			
2/15/2002	1:31:52	47	640	10.67	401	22.65	0.453	
2/15/2002	1:41:52	47	650	10.83	409			
2/15/2002	1:51:52	47	660	11.00	417			
2/15/2002	2:01:52	46	670	11.17	424			
2/15/2002	2:11:52	46	680	11.33	432			
2/15/2002	2:21:52	46	690	11.50	440			
2/15/2002	2:31:52	46	700	11.67	447			
2/15/2002	2:41:52	46	710	11.83	455			
2/15/2002	2:51:52	46	720	12.00	463			
2/15/2002	3:01:52	46	730	12.17	470			
2/15/2002	3:11:52	46	740	12.33	478			
2/15/2002	3:21:52	46	750	12.50	486			
2/15/2002	3:31:52	46	760	12.67	493			
2/15/2002	3:41:52	46	770	12.83	501			
2/15/2002	3:51:52	46	780	13.00	509			
untarped	4:01:52	46	790	13.17	516			
	4:11:52	44	800	13.33	520			
	4:21:52	42	810	13.50	524			
	4:31:52	26	820	13.67	528			
	4:41:52	23	830	13.83	532			
	4:51:52	23	840	14.00	535			
	5:01:52	23	850	14.17	539			
	5:11:52	23	860	14.33	543	30.59	0.612	
	5:21:52	23	870	14.50	547			
	5:31:52	23	880	19.00	650	36.87	0.738	
		23	890	96.00	2421	38.23	0.765	
		23	900	168.00	4077	38.55	0.772	
		23	910	650.00	15163	47.36	0.948	

Strength Age Data

Mix C
Trial 3

Test #: 8 Date: March 5/02 Bed #: 5

Time Batched: 2:45pm (D14:49:16) (21 Mix Design: HC-1 300-30 __900 -10 _____-FA
Time Extruded: 3:30pm
Time Samples cut: 4:15pm

Time 28-day in tank: 8:50pm
Time Bed Tarped: 4:15pm

Time Bed Untarped: 4:00am
Concrete Temp.: 15°C @ 4:15am

Ambient Temp.: 14°C @ 4:15pm
Consistency: wet

Actual Quantities: (batch = 2 cuy)

								In bed
Type 30	305	lbs/2yd³	90	kg/m³	Hobo #	1B		
Type 10	918	lbs/2yd³	272	kg/m³	Time laun.	4:00pm	4:15pm	
FA	0	lbs/2yd³	0	kg/m³	Hobo #			
Sand	4395	lbs/2yd³	1304	kg/m³	Time laun.			
Stone	3585	lbs/2yd³	1063	kg/m³				
730 fcs	48	oz/2yd³	421	mL/m³				

cylinder break: 4133 psi at 14 hrs

Sample ID	Test Age	Time	Time Extracted	Time In Tank	Tank Temp.	Core Size (L)	Core Size (L)	Density	Density	Strength	Average	Strength	Average	Type of break	StDev	Difference Ave. - Stren.	Not Included in Average	New Average
	(hr)	(at break)	(from bed)		(°C)	(mm)	(inches)	(kg/m³)	(pcf)	(Mpa)	(Mpa)	(psi)	(psi)		(Mpa)	(Mpa)		(Mpa)
	6	8:45pm	8:30pm		22	101.6	4	2357	147.1	13.46		1951		x		0.50		
	6					101.6	4	2357	147.1	13.57		1968		x		0.38		
	6					101.6	4	2381	148.6	16.71		2423		x		-2.75	x	
	6					101.6	4	2357	147.1	12.09	13.96	1753	2024	c	1.96	1.87		13.04
	7	9:55pm	9:35pm		23	101.6	4	2357	147.1	24.61		3568		x		-1.29	x	
	7					101.6	4	2429	151.6	23.07		3345		x		0.25		
	7					101.6	4	2357	147.1	21.96		3184		x		1.36	x	
	7					93.3	3-5/8	2331	145.5	23.63	23.32	3426	3381	x	1.11	-0.31		23.35
	8.6	11:25pm	11:10pm		24	101.6	4	2357	147.1	24.90		3611		x		0.12		
	8.6					101.6	4	2357	147.1	26.60		3857		x		-1.58	x	
	8.6					101.6	4	2331	145.5	24.77		3592		x		0.25		
	8.6					101.6	4	2381	148.6	23.81	25.02	3452	3628	x	1.16	1.21	x	24.84
	15.25	5:05am	4:22am	5:15am	23	101.6	4	2429	151.6	32.42		4701		x		-1.51		
	15.25					101.6	4	2357	147.1	30.31		4395		x		0.60		
	15.25					101.6	4	2429	151.6	28.58		4144		x		2.33	x	
	15.25					101.6	4	2331	145.5	32.33	30.91	4688	4482	x	1.83	-1.42		31.69
8-24-A	24.5	3:10pm			23	101.6	4	2331	145.5	31.19		4523		x		2.15	x	
8-24-B						101.6	4	2357	147.1	33.29		4827		x		0.06		
8-24-C						101.6	4	2357	147.1	34.12		4948		c		-0.78		
8-24-D						101.6	4	2357	147.1	34.77	33.34	5042	4835	split	1.56	-1.43		34.06
8-3-A	72	2:00pm	6:00am	6:55am		101.6	4	2429	151.6	39.90		5785		x		0.41		
8-3-B						98.4	3-7/8	2432	151.8	43.50		6307		x		-3.19	x	
8-3-C						98.4	3-7/8	2457	153.4	38.88		5638		x		1.42		
8-3-D						98.4	3-7/8	2432	151.8	38.93	40.30	5645	5844	x	2.18	1.37		39.24
8-7-A	168	2:47pm				104.8	4-1/8	2379	148.5	45.98		6667		x		-1.95		
8-7-B	168					104.8	4-1/8	2425	151.4	47.30		6859		c		-3.27	x	
8-7-C	168					104.8	4-1/8	2379	148.5	39.99		5799		c		4.04		
8-7-D	168					104.8	4-1/8	2425	151.4	42.85	44.03	6213	6385	x	3.28	1.18		42.94
8-28-A	674	5:00pm			23	104.8	4-1/8	2381	148.6	54.09		7843		x		-2.22	x	
8-28-B						101.6	4	2429	151.6	52.66		7636		s		-0.79		
8-28-C						101.6	4	2381	148.6	49.38		7160		s		2.49	x	
8-28-D						101.6	4	2381	148.6	51.35	51.87	7446	7521	x	2.00	0.52		52.01
8-28S-A	674	5:20pm	4:15pm	8:50pm	23	101.6	4	2429	151.6	60.01		8702		x		-1.17	x	
8-28S-B						101.6	4	2405	150.1	58.05		8417		x		0.80		
8-28S-C						101.6	4	2405	150.1	57.77		8376		x		1.08		
8-28S-D						101.6	4	2429	151.6	59.57	58.85	8637	8533	x	1.11	-0.72		58.46

x=conical break c=corner break s= vertical split break

Temperature Log Data and Calculated Maturity						Limiting, Su	Mix	C
			10 min =	0.16667	hours	56.28	Trial	3
Date	Time	Temp, T (C)	Age, t (min)	Age, t (hr)	Maturity, M (C-hrs)	Strength, S (MPa)	Relative, S/Su	
					0 datum			
time mixed	14:40:00	20	0	0.00	0			
	14:50:00	20	10	0.17	3.33			
	15:00:00	20	20	0.33	6.67			
	15:10:00	20	30	0.50	10.00			
	15:20:00	20	40	0.67	13.33			
	15:30:00	20	50	0.83	16.67			
	15:40:00	20	60	1.00	20.00			
	15:50:00	20	70	1.17	23.33			
3/5/2002	16:00:22	20	80	1.33	26.67			
3/5/2002	16:10:22	20	90	1.50	30.00			
3/5/2002	16:20:22	20	100	1.67	33.33			
3/5/2002	16:30:22	22	110	1.83	37.00			
3/5/2002	16:40:22	23	120	2.00	40.83			
3/5/2002	16:50:22	24	130	2.17	44.83			
3/5/2002	17:00:22	26	140	2.33	49.17			
3/5/2002	17:10:22	27	150	2.50	53.67			
3/5/2002	17:20:22	28	160	2.67	58.33			
3/5/2002	17:30:22	30	170	2.83	63.33			
3/5/2002	17:40:22	32	180	3.00	68.67			
3/5/2002	17:50:22	33	190	3.17	74.17			
3/5/2002	18:00:22	35	200	3.33	80.00			
3/5/2002	18:10:22	36	210	3.50	86.00			
3/5/2002	18:20:22	38	220	3.67	92.33			
3/5/2002	18:30:22	40	230	3.83	99.00			
3/5/2002	18:40:22	41	240	4.00	105.83			
3/5/2002	18:50:22	41	250	4.17	112.67			
3/5/2002	19:00:22	43	260	4.33	119.83			
3/5/2002	19:10:22	44	270	4.50	127.17			
3/5/2002	19:20:22	46	280	4.67	134.83			
3/5/2002	19:30:22	46	290	4.83	142.50			
3/5/2002	19:40:22	48	300	5.00	150.50			
3/5/2002	19:50:22	48	310	5.17	158.50			
3/5/2002	20:00:22	49	320	5.33	166.67			
3/5/2002	20:10:22	49	330	5.50	174.83			
3/5/2002	20:20:22	50	340	5.67	183.17			
3/5/2002	20:30:22	50	350	5.83	191.50			
3/5/2002	20:40:22	51	360	**6.00**	**200.00**	**13.04**	**0.232**	
3/5/2002	20:50:22	51	370	6.17	208.50			
3/5/2002	21:00:22	51	380	6.33	217.00			
3/5/2002	21:10:22	51	390	6.50	225.50			
3/5/2002	21:20:22	51	400	6.67	234.00			
3/5/2002	21:30:22	51	410	6.83	242.50			
3/5/2002	21:40:22	50	420	7.00	250.83			
3/5/2002	21:50:22	50	430	**7.17**	**259.17**	**23.35**	**0.415**	
3/5/2002	22:00:22	49	440	7.33	267.33			
3/5/2002	22:10:22	49	450	7.50	275.50			
3/5/2002	22:20:22	49	460	7.67	283.67			
3/5/2002	22:30:22	48	470	7.83	291.67			
3/5/2002	22:40:22	48	480	8.00	299.67			
3/5/2002	22:50:22	48	490	8.17	307.67			
3/5/2002	23:00:22	47	500	8.33	315.50			
3/5/2002	23:10:22	47	510	8.50	323.33			
3/5/2002	23:20:22	47	520	**8.67**	**331.17**	**24.84**	**0.441**	
3/5/2002	23:30:22	48	530	8.83	339.17			
3/5/2002	23:40:22	48	540	9.00	347.17			
3/5/2002	23:50:22	48	550	9.17	355.17			
3/6/2002	0:00:22	49	560	9.33	363.33			
3/6/2002	0:10:22	49	570	9.50	371.50			
3/6/2002	0:20:22	49	580	9.67	379.67			
3/6/2002	0:30:22	49	590	9.83	387.83			
3/6/2002	0:40:22	49	600	10.00	396.00			
3/6/2002	0:50:22	49	610	10.17	404.17			
3/6/2002	1:00:22	49	620	10.33	412.33			
3/6/2002	1:10:22	49	630	10.50	420.50			
3/6/2002	1:20:22	49	640	10.67	428.67			
3/6/2002	1:30:22	49	650	10.83	436.83			

Temperature Log Data and Calculated Maturity						Limiting, Su	Mix	C
			10 min =	0.16667	hours	56.28	Trial	3
Date	Time	Temp, T (C)	Age, t (min)	Age, t (hr)	Maturity, M (C-hrs)	Strength, S (MPa)	Relative, S/Su	
3/6/2002	1:40:22	49	660	11.00	445.00			
3/6/2002	1:50:22	49	670	11.17	453.17			
3/6/2002	2:00:22	49	680	11.33	461.33			
3/6/2002	2:10:22	49	690	11.50	469.50			
3/6/2002	2:20:22	49	700	11.67	477.67			
3/6/2002	2:30:22	49	710	11.83	485.83			
3/6/2002	2:40:22	49	720	12.00	494.00			
3/6/2002	2:50:22	49	730	12.17	502.17			
3/6/2002	3:00:22	49	740	12.33	510.33			
3/6/2002	3:10:22	49	750	12.50	518.50			
3/6/2002	3:20:22	49	760	12.67	526.67			
3/6/2002	3:30:22	49	770	12.83	534.83			
3/6/2002	3:40:22	49	780	13.00	543.00			
3/6/2002	3:50:22	49	790	13.17	551.17			
untarped	4:00:22	48	800	13.33	559.17			
3/6/2002	4:10:22	43	810	13.50	563.00			
3/6/2002	4:20:22	42	820	13.67	566.83			
		23	830	15.25	603.25	31.69	0.563	
		23	840	24.50	816.00	34.06	0.605	
		23	850	72.00	1908.50	39.24	0.697	
		23	860	168.00	4116.50	42.94	0.763	
		23	870	674.00	15754.50	52.01	0.924	

Strength Age Data

Mix D
Trial 1

Test #: 9 Date: March 6/02 Bed #: 2

Time Batched: 3:35pm (D15:41:14) (4) Mix Design: HC-1 300-30 _700 -10 _200 -FA
Time Extruded: 4:00pm
Time Samples cut: 4:15pm
Time 28-day in tank: 10:50pm
Time Bed Tarped: 4:25pm
Time Bed Untarped: 4:00am
Concrete Temp.: 15°C @ 4:10am

Actual Quantities: (batch = 2 cuy)

							in bed
Type 30	301	lbs/2yd^3	89	kg/m^3	Hobo #	1A	
Type 10	739	lbs/2yd^3	219	kg/m^3	Time laun.	3:50pm	
FA	139	lbs/2yd^3	41	kg/m^3	Hobo #	1B	
Sand	4380	lbs/2yd^3	1299	kg/m^3	Time laun.	3:50pm	
Stone	3610	lbs/2yd^3	1071	kg/m^3			
730 fcs	48	oz/2yd^3	421	mL/m^3	cylinder break:		

Ambient Temp.: 14°C @ 4:15pm
Consistency: dry (whisper)

Sample ID	Test Age	Time	Time Extracted	Time In Tank	Tank Temp.	Core Size (L)	Core Size (L)	Density	Density	Strength	Average	Strength	Average	Type of break	StDev	Difference Ave. - Stren.	Not Included in Average	New Average
	(hr)	(at break)	(from bed)		(°C)	(mm)	(inches)	(kg/m^3)	(pcf)	(Mpa)	(Mpa)	(psi)	(psi)		(Mpa)	(Mpa)		(Mpa)
	6.75	10:15pm	10:00pm		23	101.6	4	2405	150.1	10.43		1513		x				
						98.4	3-7/8	2406	150.2	10.29	10.36	1492	1503	x				10.36
	8.3	11:50pm	11:35pm		24	101.6	4	2405	150.1	19.79		2869		x		0.75		
						101.6	4	2405	150.1	20.63		2992		x		-0.10		
						101.6	4	2429	151.6	19.86		2880		x		0.67		
						101.6	4	2429	151.6	21.85	20.53	3168	2977	x	0.96	-1.32	x	20.09
	9	12:40am	12:30am		24	101.6	4	2453	153.1	22.60		3277		x				
						101.6	4	2429	151.6	19.90	21.25	2885	3081	x				21.25
	14	5:35am	5:10am		24	101.6	4	2429	151.6	32.96		4779		x		0.23		
						101.6	4	2413	150.6	34.52		5005		x		-1.33		
						101.6	4	2381	148.6	30.43		4413		x		2.76	x	
						101.6	4	2413	150.6	34.86	33.19	5054	4813	x	2.02	-1.66		34.11
9-24-A	23	2:40pm		6:35pm	23	101.6	4	2453	153.1	33.31		4830		x		2.65	x	
9-24-B						101.6	4	2405	150.1	36.59		5306		x		-0.63		
9-24-C						101.6	4	2453	153.1	37.99	35.96	5508	5215	x	2.40	-2.02		37.29
9-3-A	76	7:45pm	6:20am	7:25am		101.6	4	2429	151.6	44.10		6394		s		-2.10		
9-3-B						101.6	4	2429	151.6	40.81		5917		x		1.19		
9-3-C						101.6	4	2381	148.6	36.92		5353		x		5.08	x	
9-3-D						101.6	4	2429	151.6	46.15	41.99	6692	6089	x	4.04	-4.16	x	42.45
9-7-A	169	5:00pm			23	101.6	4	2429	151.6	47.21		6846		x		-0.50		
9-7-B						101.6	4	2429	151.6	48.49		7031		x		-1.78		
9-7-C						101.6	4	2429	151.6	49.94		7241		x		-3.23		
9-7-D						101.6	4	2405	150.1	41.20	46.71	5974	6773	x	3.84	5.51	x	48.55
9-28-A	674	5:40pm			23	101.6	4	2453	153.1	62.04		8996		x		-5.46	x	
9-28-B						101.6	4	2381	148.6	53.90		7816		x		2.68		
9-28-C						101.6	4	2453	153.1	56.47		8188		x		0.11		
9-28-D						101.6	4	2429	151.6	53.91	56.58	7817	8204	x	3.84	2.67		54.76
9-28S-A	674	5:50pm	4:15pm	10:50pm	23	101.6	4	2429	151.6	67.90		9846		x		-5.46	x	
9-28S-B						101.6	4	2405	150.1	60.48		8770		c		1.96		
9-28S-C						101.6	4	2405	150.1	61.10		8860		x		1.34		
9-28S-D						101.6	4	2405	150.1	60.28	62.44	8740	9054	s	3.66	2.17		60.62

x=conical break c=corner break s= vertical split break (S$_{S28}$ - S$_{28}$)/S$_{S28}$ 9.39%

Temperature Log Data and Calculated Maturity						Limiting, Su	Mix	D
			10 min =	0.16667	hours	61.10	Trial	1
Date	Time	Temp, T (C)	Age, t (min)	Age, t (hr)	Maturity, M (C-hrs)	Strength, S (MPa)	Relative, S/Su	
					0 datum			
time mixed	15:40:00	15	0	0.00	0			
3/6/2002	15:50:25	15	10	0.17	3			
3/6/2002	16:00:25	15	20	0.33	5			
3/6/2002	16:10:25	15	30	0.50	8			
3/6/2002	16:20:25	15	40	0.67	10			
3/6/2002	16:30:25	15	50	0.83	13			
3/6/2002	16:40:25	16	60	1.00	15			
3/6/2002	16:50:25	17	70	1.17	18			
3/6/2002	17:00:25	19	80	1.33	21			
3/6/2002	17:10:25	19	90	1.50	24			
3/6/2002	17:20:25	20	100	1.67	28			
3/6/2002	17:30:25	21	110	1.83	31			
3/6/2002	17:40:25	22	120	2.00	35			
3/6/2002	17:50:25	23	130	2.17	39			
3/6/2002	18:00:25	24	140	2.33	43			
3/6/2002	18:10:25	25	150	2.50	47			
3/6/2002	18:20:25	26	160	2.67	51			
3/6/2002	18:30:25	27	170	2.83	56			
3/6/2002	18:40:25	28	180	3.00	60			
3/6/2002	18:50:25	28	190	3.17	65			
3/6/2002	19:00:25	29	200	3.33	70			
3/6/2002	19:10:25	30	210	3.50	75			
3/6/2002	19:20:25	30	220	3.67	80			
3/6/2002	19:30:25	31	230	3.83	85			
3/6/2002	19:40:25	32	240	4.00	90			
3/6/2002	19:50:25	33	250	4.17	96			
3/6/2002	20:00:25	34	260	4.33	102			
3/6/2002	20:10:25	34	270	4.50	107			
3/6/2002	20:20:25	35	280	4.67	113			
3/6/2002	20:30:25	36	290	4.83	119			
3/6/2002	20:40:25	36	300	5.00	125			
3/6/2002	20:50:25	36	310	5.17	131			
3/6/2002	21:00:25	36	320	5.33	137			
3/6/2002	21:10:25	37	330	5.50	143			
3/6/2002	21:20:25	37	340	5.67	149			
3/6/2002	21:30:25	36	350	5.83	155			
3/6/2002	21:40:25	35	360	6.00	161			
3/6/2002	21:50:25	34	370	6.17	167			
3/6/2002	22:00:25	35	380	6.33	173			
3/6/2002	22:10:25	36	390	6.50	179			
3/6/2002	22:20:25	36	400	**6.67**	**185**	**10.36**	**0.170**	
3/6/2002	22:30:25	36	410	6.83	191			
3/6/2002	22:40:25	37	420	7.00	197			
3/6/2002	22:50:25	37	430	7.17	203			
3/6/2002	23:00:25	37	440	7.33	209			
3/6/2002	23:10:25	37	450	7.50	215			
3/6/2002	23:20:25	38	460	7.67	222			
3/6/2002	23:30:25	39	470	7.83	228			
3/6/2002	23:40:25	38	480	8.00	235			
3/6/2002	23:50:25	38	490	**8.17**	**241**	**20.09**	**0.329**	
3/7/2002	0:00:25	37	500	8.33	247			
3/7/2002	0:10:25	37	510	8.50	253			
3/7/2002	0:20:25	38	520	8.67	260			
3/7/2002	0:30:25	38	530	8.83	266			
3/7/2002	0:40:25	38	540	**9.00**	**272**	**21.25**	**0.348**	
3/7/2002	0:50:25	38	550	9.17	279			
3/7/2002	1:00:25	38	560	9.33	285			
3/7/2002	1:10:25	38	570	9.50	291			
3/7/2002	1:20:25	38	580	9.67	298			
3/7/2002	1:30:25	38	590	9.83	304			
3/7/2002	1:40:25	38	600	10.00	310			
3/7/2002	1:50:25	38	610	10.17	317			
3/7/2002	2:00:25	38	620	10.33	323			

Temperature Log Data and Calculated Maturity						Limiting, Su	Mix	D
			10 min =	0.16667	hours	61.10	Trial	1
Date	Time	Temp, T (C)	Age, t (min)	Age, t (hr)	Maturity, M (C-hrs)	Strength, S (MPa)	Relative, S/Su	
3/7/2002	2:10:25	38	630	10.50	329			
3/7/2002	2:20:25	38	640	10.67	336			
3/7/2002	2:30:25	38	650	10.83	342			
3/7/2002	2:40:25	38	660	11.00	348			
3/7/2002	2:50:25	39	670	11.17	355			
3/7/2002	3:00:25	39	680	11.33	361			
3/7/2002	3:10:25	39	690	11.50	368			
3/7/2002	3:20:25	39	700	11.67	374			
3/7/2002	3:30:25	39	710	11.83	381			
3/7/2002	3:40:25	39	720	12.00	387			
3/7/2002	3:50:25	39	730	12.17	394			
3/7/2002	4:00:25	39	740	12.33	400			
3/7/2002	4:10:25	37	750	12.50	406			
untarped	4:20:25	35	760	12.67	412			
		23	770	14.00	443	34.11	0.558	
		23	780	23.00	650	37.29	0.610	
		23	790	76.00	1869	42.45	0.695	
		23	800	169.00	4008	48.55	0.795	
		23	810	674.00	15623	54.76	0.896	

Strength Age Data

Mix D
Trial 2

Test #: __ 13 Date: ___ March 26/02 Bed #: _ 2

Time Batched: _____ D15:53:13 (3)
Time Extruded: ____ 4:00pm
Time Samples cut: _ 4:35pm

Time 28-day in tank: 11:00pm
Time Bed Tarped: __ 5:40pm

Time Bed Untarped: 3:50pm
Concrete Temp.:___ 15°C @ 4:30pm

Ambient Temp.:____ 14°C @ 4:30pm
Consistency: ______ wet

Mix Design: HC-1 300-30 _700 -10 _200 -FA
Actual Quantities: (batch = 2 cuy)

							in bed
Type 30	302	lbs/2yds	90	kg/m³	Hobo #	1A	
Type 10	708	lbs/2yds	210	kg/m³	Time laun.	4:20pm	
FA	222	lbs/2yds	66	kg/m³	Hobo #	1B	
Sand	4390	lbs/2yds	1302	kg/m³	Time laun.	4:20pm	
Stone	3600	lbs/2yds	1068	kg/m³	RH	4:15pm	
730 fcs	48	oz/2yd³	421	mL/m³	cylinder break:_		

Sample ID	Test Age	Time	Time Extracted	Time In Tank	Tank Temp.	Core Size (L)	Core Size (L)	Density	Density	Strength	Average	Strength	Average	Type of break	StDev	Difference Ave. - Stren.	Not Included in Average	New Average
	(hr)	(at break)	(from bed)		(°C)	(mm)	(inches)	(kg/m³)	(pcf)	(Mpa)	(Mpa)	(psi)	(psi)		(Mpa)	(Mpa)		(Mpa)
	6.5	10:40pm	10:23pm		22	101.6	4	2357	147.1	12.18		1766		c		1.43		
						101.6	4	2405	150.1	15.26		2212		x		-1.65	x	
						101.6	4	2405	150.1	14.40		2088		c		-0.79		
						101.6	4	2357	147.1	12.59	13.61	1825	1973	c	1.46	1.02		13.06
	7.5	11:40pm	11:25pm		23	101.6	4	2429	151.6	21.55		3125		x		-1.81	x	
						101.6	4	2405	150.1	19.21		2785		x		0.54		
						101.6	4	2432	151.8	19.41		2815		x		0.33		
						98.4	3-7/8	2429	151.6	18.80	19.74	2726	2863	x	1.23	0.94		19.14
	8.5	12:40am	12:25am		24	101.6	4	2429	151.6	25.85		3748		c		-1.77		
						101.6	4	2405	150.1	22.48		3259		x		1.61		
						101.6	4	2381	148.6	21.68		3144		x		2.40	x	
						101.6	4	2405	150.1	26.32	24.08	3816	3492	x	2.34	-2.24		24.88
	13.5	5:05am	4:48am		25	101.6	4	2381	148.6	27.46		3982		x		1.86	x	
						101.6	4	2405	150.1	32.00		4640		x		-2.68		
						101.6	4	2357	147.1	28.02		4063		x		1.30	x	
						101.6	4	2405	150.1	29.81	29.32	4322	4252	x	2.05	-0.48		30.90
13-24-A	26	5:20pm	6:30am	7:00am	21	101.6	4	2357	147.1	29.88		4332		split		1.21		
13-24-B						101.6	4	2357	147.1	30.75		4459		x		0.33		
13-24-C						101.6	4	2381	148.6	34.10		4944		x		-3.02	x	
13-24-D						101.6	4	2381	148.6	29.60	31.08	4292	4507	x	2.07	1.48		30.08
13-3-A	72					101.6	4	2357	147.1	39.31		5700		x		-0.41		
13-3-B						101.6	4	2357	147.1	38.51		5584		s		0.39		
13-3-C						101.6	4	2357	147.1	37.94		5501		s		0.97	x	
13-3-D						101.6	4	2405	150.1	39.86	38.91	5780	5641	x	0.85	-0.96	x	38.91
13-7-A	168	4:40pm			23	101.6	4	2429	151.6	42.98		6232		c		-1.53		
13-7-B						101.6	4	2405	150.1	36.76		5330		c		4.69	x	
13-7-C						101.6	4	2429	151.6	43.18		6261		c		-1.73		
13-7-D						101.6	4	2381	148.6	42.89	41.45	6219	6011	x	3.13	-1.44		43.02
13-28-A	677	9:30pm			24	101.6	4	2381	148.6	50.59		7335		x		4.20	x	
13-28-B						101.6	4	2429	151.6	56.94		8256		c		-2.15		
13-28-C						101.6	4	2429	151.6	55.59		8061		c		-0.80		
13-28-D						101.6	4	2405	150.1	56.04	54.79	8126	7945	x	2.86	-1.25		56.19
13-28S-A	677	9:35pm	4:35pm	11:00pm	24	101.6	4	2405	150.1	54.60		7917		x		0.38		
13-28S-B						101.6	4	2405	150.1	55.88		8102		x		-0.89	x	
13-28S-C						101.6	4	2381	148.6	54.52		7905		s		0.46		
13-28S-D						101.6	4	2381	148.6	54.93	54.98	7965	7972	x	0.62	0.05		54.68

x=conical break c=corner break s= vertical split break

Temperature Log Data and Calculated Maturity						Limiting, Su	Mix	D
			10 min =	0.16667	hours	62.93	Trial	2
Date	Time	Temp, T (C)	Age, t (min)	Age, t (hr)	Maturity, M (C-hrs)	Strength, S (MPa)	Relative, S/Su	
					0 datum			
time mixed	15:57	17	0	0.00	0			
	16:07	17	10	0.17	3			
3/26/2002	16:17:44	17	20	0.33	6			
3/26/2002	16:27:44	17	30	0.50	9			
3/26/2002	16:37:44	19	40	0.67	12			
3/26/2002	16:47:44	18	50	0.83	15			
3/26/2002	16:57:44	18	60	1.00	18			
3/26/2002	17:07:44	19	70	1.17	21			
3/26/2002	17:17:44	18	80	1.33	24			
3/26/2002	17:27:44	19	90	1.50	27			
3/26/2002	17:37:44	20	100	1.67	30			
3/26/2002	17:47:44	21	110	1.83	34			
3/26/2002	17:57:44	22	120	2.00	38			
3/26/2002	18:07:44	22	130	2.17	41			
3/26/2002	18:17:44	23	140	2.33	45			
3/26/2002	18:27:44	24	150	2.50	49			
3/26/2002	18:37:44	24	160	2.67	53			
3/26/2002	18:47:44	25	170	2.83	57			
3/26/2002	18:57:44	26	180	3.00	62			
3/26/2002	19:07:44	27	190	3.17	66			
3/26/2002	19:17:44	28	200	3.33	71			
3/26/2002	19:27:44	29	210	3.50	76			
3/26/2002	19:37:44	30	220	3.67	81			
3/26/2002	19:47:44	32	230	3.83	86			
3/26/2002	19:57:44	33	240	4.00	91			
3/26/2002	20:07:44	34	250	4.17	97			
3/26/2002	20:17:44	35	260	4.33	103			
3/26/2002	20:27:44	36	270	4.50	109			
3/26/2002	20:37:44	37	280	4.67	115			
3/26/2002	20:47:44	38	290	4.83	121			
3/26/2002	20:57:44	39	300	5.00	128			
3/26/2002	21:07:44	39	310	5.17	134			
3/26/2002	21:17:44	39	320	5.33	141			
3/26/2002	21:27:44	39	330	5.50	147			
3/26/2002	21:37:44	39	340	5.67	154			
3/26/2002	21:47:44	39	350	5.83	160			
3/26/2002	21:57:44	41	360	6.00	167			
3/26/2002	22:07:44	41	370	6.17	174			
3/26/2002	22:17:44	41	380	6.33	181			
3/26/2002	22:27:44	41	390	6.50	188			
3/26/2002	22:37:44	42	400	**6.67**	**195**	**13.06**	**0.207**	
3/26/2002	22:47:44	42	410	6.83	202			
3/26/2002	22:57:44	42	420	7.00	209			
3/26/2002	23:07:44	42	430	7.17	216			
3/26/2002	23:17:44	42	440	7.33	223			
3/26/2002	23:27:44	43	450	7.50	230			
3/26/2002	23:37:44	43	460	**7.67**	**237**	**19.14**	**0.304**	
3/26/2002	23:47:44	43	470	7.83	244			
3/26/2002	23:57:44	42	480	8.00	251			
3/27/2002	0:07:44	42	490	8.17	258			
3/27/2002	0:17:44	42	500	8.33	265			
3/27/2002	0:27:44	42	510	8.50	272			
3/27/2002	0:37:44	42	520	**8.67**	**279**	**24.88**	**0.395**	
3/27/2002	0:47:44	42	530	8.83	286			
3/27/2002	0:57:44	42	540	9.00	293			
3/27/2002	1:07:44	42	550	9.17	300			
3/27/2002	1:17:44	42	560	9.33	307			
3/27/2002	1:27:44	42	570	9.50	314			
3/27/2002	1:37:44	42	580	9.67	321			
3/27/2002	1:47:44	42	590	9.83	328			
3/27/2002	1:57:44	42	600	10.00	335			
3/27/2002	2:07:44	42	610	10.17	342			
3/27/2002	2:17:44	42	620	10.33	349			

Temperature Log Data and Calculated Maturity						Limiting, Su	Mix	D
			10 min =	0.16667	hours	62.93	Trial	2
Date	Time	Temp, T (C)	Age, t (min)	Age, t (hr)	Maturity, M (C-hrs)	Strength, S (MPa)	Relative, S/Su	
3/27/2002	2:27:44	42	630	10.50	356			
3/27/2002	2:37:44	42	640	10.67	363			
3/27/2002	2:47:44	42	650	10.83	370			
3/27/2002	2:57:44	43	660	11.00	377			
3/27/2002	3:07:44	43	670	11.17	385			
3/27/2002	3:17:44	43	680	11.33	392			
3/27/2002	3:27:44	43	690	11.50	399			
3/27/2002	3:37:44	43	700	11.67	406			
3/27/2002	3:47:44	41	710	11.83	413			
3/27/2002	3:57:44	40	720	12.00	420			
3/27/2002	4:07:44	39	730	12.17	426			
3/27/2002	4:17:44	37	740	12.33	432			
untarped	4:27:44	36	750	12.50	438			
		23		13.50	461	30.90	0.491	
		23		26.00	749	30.08	0.478	
		23		72.00	1807	38.91	0.618	
		23		168.00	4015	43.02	0.684	
		23		677.00	15722	56.19	0.893	

Strength Age Data

Mix D
Trial 3

Test #: 14 Date: March 26/02 Bed #: 4

Time Batched: D15:14:52 (20)
Time Extruded: 4:00pm
Time Samples cut: 4:30pm + 5:30pm

Time 28-day in tank: 10:45pm
Time Bed Tarped: 6:00pm

Time Bed Untarped: 10
Concrete Temp.: 22°C @ 6:05pm

Ambient Temp.: 18°C @ 6:05pm
Consistency: -

Mix Design: HC-1 300-30 _700 -10 _200 -FA
Actual Quantities: (batch = 2 cuy)

Type 30	300	lbs/2yd³	89	kg/m³	in bed Hobo #	1A	
Type 10	680	lbs/2yd³	202	kg/m³	Time laun.	6:00pm	6:03pm
FA	216	lbs/2yd³	64	kg/m³	Hobo #	1B	
Sand	4390	lbs/2yd³	1302	kg/m³	Time laun.	6:00pm	6:03pm
Stone	3565	lbs/2yd³	1058	kg/m³	RH	6:00pm	
730 fcs	48	oz/2yd³	421	mL/m³	cylinder break:		

Sample ID	Test Age	Time	Time Extracted	Time In Tank	Tank Temp.	Core Size (L)	Core Size (L)	Density	Density	Strength	Average	Strength	Average	Type of break	StDev	Difference Ave. - Stren.	Not Included in Average	New Average
	(hr)	(at break)	(from bed)		(°C)	(mm)	(inches)	(kg/m³)	(pcf)	(Mpa)	(Mpa)	(psi)	(psi)		(Mpa)	(Mpa)		(Mpa)
		9:30pm	9:20pm		23	101.6	4	2357	147.1	10.77		1561		x		0.75		
						101.6	4	2405	150.1	12.59		1825				-1.07	x	
						93.3	3-5/8	2385	148.9	11.19	11.51	1623	1670		0.95	0.32		10.98
		10:35pm	10:25pm		23	101.6	4	2381	148.6	15.78		2288		c		3.12	x	
						101.6	4	2405	150.1	18.82		2729		x		0.08		
						101.6	4	2453	153.1	20.95		3038		x		-2.05		
						95.3	3-3/4	2409	150.4	20.05	18.90	2907	2741	s	2.26	-1.15		19.94
		12:10pm	11:45pm		23	101.6	4	2357	147.1	22.90		3321		x		0.27		
						101.6	4	2357	147.1	22.87		3316		x		0.31		
						101.6	4	2357	147.1	23.75	23.17	3444	3360	x	0.50	-0.58	x	22.89
		9:30am	9:17am		23	101.6	4	2381	148.6	30.31		4395		s		-0.79		
						101.6	4	2381	148.6	30.06		4359		x		-0.54		
						101.6	4	2381	148.6	28.18	29.52	4086	4280	c	1.17	1.34	x	30.19
14-4-A	24	4:00pm	10:30am	11:30am	23	101.6	4	2331	145.5	36.92		5353		c		1.88	x	
14-4-B						101.6	4	2381	148.6	39.58		5739		x		-0.78		
14-4-C						101.6	4	2405	150.1	39.69		5755		x		-0.89		
14-4-D						101.6	4	2381	148.6	39.01	38.80	5657	5626	s	1.29	-0.21		39.43
14-7-A		4:50pm			23	101.6	4	2381	148.6	41.14		5965		x		-1.48	x	
14-7-B						101.6	4	2357	147.1	37.86		5490		x		1.79	x	
14-7-C						101.6	4	2381	148.6	40.20		5829		x		-0.55		
14-7-D						101.6	4	2357	147.1	39.41	39.65	5715	5750	x	1.39	0.24		39.81
14-28-A		5:00pm			23	101.6	4	2381	148.6	48.51		7034		c		0.35		
14-28-B						101.6	4	2405	150.1	47.26		6853		x		1.60	x	
14-28-C						101.6	4	2381	148.6	50.72		7354		x		-1.86	x	
14-28-D						101.6	4	2365	147.6	48.95	48.86	7098	7085	x	1.43	-0.09		48.73
13-28S-A		5:00pm	6:00pm	10:45pm	23	101.6	4	2429	151.6	56.11		8136		x		-0.15		
13-28S-B						101.6	4	2429	151.6	57.51		8339		x		-1.55	x	
13-28S-C						101.6	4	2405	150.1	55.38		8030		s		0.58		
13-28S-D						101.6	4	2405	150.1	54.86	55.96	7954	8115	x	1.15	1.11		55.45

x=conical break c=corner break s= vertical split break

Temperature Log Data and Calculated Maturity						Limiting, Su	Mix	D
			10 min =	0.16667	hours	53.03	Trial	3
Date	Time	Temp, T (C)	Age, t (min)	Age, t (hr)	Maturity, M (C-hrs)	Strength, S (MPa)	Relative, S/Su	
					0 datum			
time mixed	3:18	20	0	0.00	0			
3/28/2002	3:28	20	10	0.17	3			
3/28/2002	3:38	20	20	0.33	7			
3/28/2002	3:48	20	30	0.50	10			
3/28/2002	3:58	20	40	0.67	13			
3/28/2002	4:08	20	50	0.83	17			
3/28/2002	4:18	20	60	1.00	20			
3/28/2002	4:28	20	70	1.17	23			
	4:38	20	80	1.33	27			
	4:48	20	90	1.50	30			
	4:58	20	100	1.67	33			
	5:08	20	110	1.83	37			
	5:18	20	120	2.00	40			
	5:28	20	130	2.17	43			
	5:38	20	140	2.33	47			
	5:48	20	150	2.50	50			
	5:58:57	20	160	2.67	53			
	6:08:57	23.4	170	2.83	57			
	6:18:57	24.3	180	3.00	61			
	6:28:57	26.3	190	3.17	66			
	6:38:57	26.3	200	3.33	70			
	6:48:57	28.2	210	3.50	75			
	6:58:57	30.2	220	3.67	80			
	7:08:57	32.2	230	3.83	85			
	7:18:57	33.1	240	4.00	91			
	7:28:57	35.1	250	4.17	97			
	7:38:57	36.1	260	4.33	103			
	7:48:57	37	270	4.50	109			
	7:58:57	38	280	4.67	115			
	8:08:57	39	290	4.83	122			
	8:18:57	40	300	5.00	128			
	8:28:57	41	310	5.17	135			
	8:38:57	41.9	320	5.33	142			
	8:48:57	43.9	330	5.50	149			
	8:58:57	43.9	340	5.67	157			
	9:08:57	43.9	350	5.83	164			
	9:18:57	43.9	360	6.00	171			
	9:28:57	43.9	370	**6.17**	**179**	**10.98**	**0.207**	
	9:38:57	44.9	380	6.33	186			
	9:48:57	44.9	390	6.50	194			
	9:58:57	45.8	400	6.67	201			
	10:08:57	45.8	410	6.83	209			
	10:18:57	45.8	420	7.00	216			
	10:28:57	44.9	430	7.17	224			
	10:38:57	44.9	440	**7.33**	**231**	**19.94**	**0.376**	
	10:48:57	43.9	450	7.50	239			
	10:58:57	43.9	460	7.67	246			
	11:08:57	43.9	470	7.83	253			
	11:18:57	43.9	480	8.00	261			
	11:28:57	44.9	490	8.17	268			
	11:38:57	44.9	500	8.33	276			
	11:48:57	44.9	510	8.50	283			
	11:58:57	45.8	520	8.67	291			
	12:08:57	45.8	530	**8.83**	**298**	**22.89**	**0.432**	
	12:18:57	45.8	540	9.00	306			
	12:28:57	45.8	550	9.17	314			
	12:38:57	45.8	560	9.33	321			
	12:48:57	45.8	570	9.50	329			
	12:58:57	46.8	580	9.67	337			
	1:08:57	46.8	590	9.83	345			
	1:18:57	46.8	600	10.00	352			
	1:28:57	46.8	610	10.17	360			

Temperature Log Data and Calculated Maturity						Limiting, Su	Mix	D
			10 min =	0.16667	hours	53.03	Trial	3
Date	Time	Temp, T (C)	Age, t (min)	Age, t (hr)	Maturity, M (C-hrs)	Strength, S (MPa)	Relative, S/Su	
	1:38:57	46.8	620	10.33	368			
	1:48:57	46.8	630	10.50	376			
	1:58:57	46.8	640	10.67	384			
	2:08:57	46.8	650	10.83	391			
	2:18:57	46.8	660	11.00	399			
	2:28:57	46.8	670	11.17	407			
	2:38:57	46.8	680	11.33	415			
	2:48:57	47.8	690	11.50	423			
	2:58:57	47.8	700	11.67	431			
	3:08:57	47.8	710	11.83	439			
	3:18:57	47.8	720	12.00	447			
	3:28:57	47.8	730	12.17	455			
	3:38:57	47.8	740	12.33	463			
	3:48:57	47.8	750	12.50	471			
	3:58:57	47.8	760	12.67	478			
	4:08:57	47.8	770	12.83	486			
	4:18:57	47.8	780	13.00	494			
	4:28:57	48.8	790	13.17	503			
	4:38:57	48.8	800	13.33	511			
	4:48:57	48.8	810	13.50	519			
	4:58:57	48.8	820	13.67	527			
	5:08:57	48.8	830	13.83	535			
	5:18:57	48.8	840	14.00	543			
	5:28:57	48.8	850	14.17	551			
	5:38:57	47.8	860	14.33	559			
	5:48:57	48.8	870	14.50	567			
	5:58:57	48.8	880	14.67	576			
	6:08:57	48.8	890	14.83	584			
	6:18:57	48.8	900	15.00	592			
	6:28:57	48.8	910	15.17	600			
	6:38:57	48.8	920	15.33	608			
	6:48:57	48.8	930	15.50	616			
	6:58:57	48.8	940	15.67	624			
	7:08:57	48.8	950	15.83	633			
	7:18:57	48.8	960	16.00	641			
	7:28:57	48.8	970	16.17	649			
	7:38:57	48.8	980	16.33	657			
	7:48:57	48.8	990	16.50	665			
	7:58:57	48.8	1000	16.67	673			
	8:08:57	48.8	1010	16.83	681			
	8:18:57	48.8	1020	17.00	689			
	8:28:57	47.8	1030	17.17	697			
	8:38:57	47.8	1040	17.33	705			
	8:48:57	47.8	1050	17.50	713			
	8:58:57	46.8	1060	17.67	721			
	9:08:57	46.8	1070	17.83	729			
	9:18:57	45.8	1080	18.00	737			
	9:28:57	43.9	1090	**18.17**	**744**	**30.19**	**0.569**	
	9:38:57	41.9	1100	18.33	751			
	9:48:57	41	1110	18.50	758			
untarped	9:58:57	39	1120	**96.00**	**2540**	**39.43**	**0.743**	
		23	1130	**169.00**	**4219**	**39.81**	**0.751**	
		23	1140	**673.00**	**15811**	**48.73**	**0.919**	

APPENDIX E – SLIPPAGE INVESTIGATION DATA

Slippage Investigation Data for March, April, and May 2002

Slipppage Investigation

Date: March 2002

Date		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total	%
Extrud. #	001				2			5	4	22						4					25	5	10			12							89	38%
	002													2			10		2														14	6%
	003													16		5			6		4												31	13%
	004																																0	0%
	005																																0	0%
	006																																0	0%
	008																																0	0%
	010																																0	0%
	Wh 8									2		11		2	3				7		4	9		4			1						43	18%
	Wh 10	1													6		9						6	35									57	24%
	Total																																234	
Bed #	1				1				1	6		11		10	3		9		7		4	5				5							62	26%
	2													2																			2	1%
	3									2				6		5			4					4									21	9%
	4	1							3	7				1	3	4			4		8			26			1						58	25%
	5									4				1							4	5	10										24	10%
	6				1			5		5					3		10				17	4	6	9		7							67	29%
	Total																																234	
Set	1							5	3	5				7	3				2		8												33	14%
	2								1	9					3		9						6	8									36	15%
	3									10		11		1	3	9	10		6		15			9									74	32%
	4				2																	9				7	1						19	8%
	5	1												12					7		10	5	10	22		5							72	31%
	Total																																234	
Cables	T				2			2	3	23		6		12	3		27		8		40	18	42	18		8							214	
	BO	2						8	1	4		13		19	4	15	33		8		30	6	8	54		16	2						223	
	BI				6									3	4				1		10	5	7	18		3							57	
	Total																																494	
Size	6																																0	0%
	8									2		11		18	3	5			10		8	6		4			1						68	29%
	10	1			2			5	4	22				2	6	4	19		4		26	8	16	35		12							166	71%
	12																																0	0%
	Total																																234	
Mix	1																																0	0%
	2				2			5		14				19																			40	17%
	3								4						6		9		8		18	15	16	8		12	1						97	41%
	4	1										11		1	3	9			6		15												46	20%
	5									10							10							31									51	22%
	Total																																234	
Rel. Str.	Fail	1													3	4	9				2	1	6										26	11%

Slipppage Investigation

April 2002

Date		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total	%
Extrud. #	001	4		2	4	12					14	7						3	11								4						61	38%
	002												4												7	9		12					32	20%
	003																			5				5	1	3					2		16	10%
	004																																0	0%
	005																																0	0%
	006				1	3						1																					5	3%
	008																																0	0%
	010																																0	0%
	Wh 8																1											4					5	3%
	Wh 10		20	20																													40	25%
	Total	4	20	22	5	15	0	0	0	0	14	8	4	0	0	0	1	3	11	5	0	0	0	5	8	12	4	16	0	0	2	0	159	
Bed #	1		8	9	1	3						8													3	9							41	26%
	2																							5				4					9	6%
	3										10														4								14	9%
	4				4														11						1	3		12			2		33	21%
	5					12														5													17	11%
	6	4	12	13							4		4				1	3									4						45	28%
	Total	4	20	22	5	15	0	0	0	0	14	8	4	0	0	0	1	3	11	5	0	0	0	5	8	12	4	16	0	0	2	0	159	
Set	1		12		1	12							4					3						5	5								42	26%
	2		8	11	3						4	7					1								3	3	4	4					48	30%
	3	4		9							10								11	5						9							48	30%
	4				1																							12			2		15	9%
	5			2		3						1																					6	4%
	Total	4	20	22	5	15	0	0	0	0	14	8	4	0	0	0	1	3	11	5	0	0	0	5	8	12	4	16	0	0	2	0	159	
Cables	T	4	20	22	5	15					14	8						3	11						7	12		16					137	
	BO												4				1			5				5	1		4						20	
	BI																														2		2	
	Total	4	20	22	5	15	0	0	0	0	14	8	4	0	0	0	1	3	11	5	0	0	0	5	8	12	4	16	0	0	2	0	159	
Size	6																																0	0%
	8																1			5				5	1	3		4			2		21	13%
	10	4	20	22	4	12					14	7	4					3	11						7	9	4	12					133	84%
	12				1	3						1																					5	3%
	Total	4	20	22	5	15	0	0	0	0	14	8	4	0	0	0	1	3	11	5	0	0	0	5	8	12	4	16	0	0	2	0	159	
Mix	1																																0	0%
	2																																0	0%
	3		20	13	5	15					4	8	4				1	3						5	8	3	4	4			2		99	62%
	4	4		9							10								11	5						9							48	30%
	5																											12					12	8%
	Total	4	20	22	5	15	0	0	0	0	14	8	4	0	0	0	1	3	11	5	0	0	0	5	8	12	4	16	0	0	2	0	159	
Rel. Str.	Fail																																0	0%

Slipppage Investigation May 2002

Date		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total	%
Extrud. #	001			10													2	5														1	18	21%
	002																					2	12	6						2		2	24	28%
	003									5																				1	6		12	14%
	004																																0	0%
	005			2				1		2						11															5		21	24%
	006								1	1						4									5								11	13%
	008																																0	0%
	010																																0	0%
	Wh 8																																0	0%
	Wh 10																																0	0%
	Total	0	0	12	0	0	0	1	1	8	0	0	0	0	0	15	2	5	0	0	0	2	12	6	5	0	0	0	0	3	11	3	86	
Bed #	1			6				1									2																9	10%
	2								1							11							1	6							6		25	29%
	3			1						5						4						2	11							1		1	25	29%
	4									1																							1	1%
	5			1														5															6	7%
	6			4						2															5					2	5	2	20	23%
	Total	0	0	12	0	0	0	1	1	8	0	0	0	0	0	15	2	5	0	0	0	2	12	6	5	0	0	0	0	3	11	3	86	
Set	1																														6	1	7	8%
	2																							6								2	8	9%
	3			1				1		2						4														1	5		14	16%
	4			6					1	6							2	5				2	1							2			25	29%
	5			5												11							11		5								32	37%
	Total	0	0	12	0	0	0	1	1	8	0	0	0	0	0	15	2	5	0	0	0	2	12	6	5	0	0	0	0	3	11	3	86	
Cables	T			10					1	2						11		5					12							3			44	
	BO			2				1		5						4						2		6	5						11	2	38	
	BI									1							2															1	4	
	Total	0	0	12	0	0	0	1	1	8	0	0	0	0	0	15	2	5	0	0	0	2	12	6	5	0	0	0	0	3	11	3	86	
Size	6																																0	0%
	8			2				1		7						11														1	11		33	38%
	10			10													2	5				2	12	6						2		3	42	49%
	12								1	1						4									5								11	13%
	Total	0	0	12	0	0	0	1	1	8	0	0	0	0	0	15	2	5	0	0	0	2	12	6	5	0	0	0	0	3	11	3	86	
Mix	1																																0	0%
	2									6														6									12	14%
	3								1							11	2					2	12							2	6	1	37	43%
	4							1								4									5					1	5	2	18	21%
	5			12						2								5															19	22%
	Total	0	0	12	0	0	0	1	1	8	0	0	0	0	0	15	2	5	0	0	0	2	12	6	5	0	0	0	0	3	11	3	86	
Rel. Str.	Fail																																0	0%

VITA AUCTORIS

Name:	Alvin Olar
Place of Birth:	Sault Ste. Marie, Ontario
Year of Birth:	1976
Education:	White Pines C&VS, Sault Ste. Marie, Ontario 1989 – 1993
	Laurentian University, Sudbury, Ontario 1994 – 1996
	University of Windsor, Windsor, Ontario 1996 – 1999 B.A.Sc.
	University of Windsor, Windsor, Ontario 1999 – 2003 M.A.Sc.